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COSMOS

ISSUE 99

COSMOS

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Finding our future in new species

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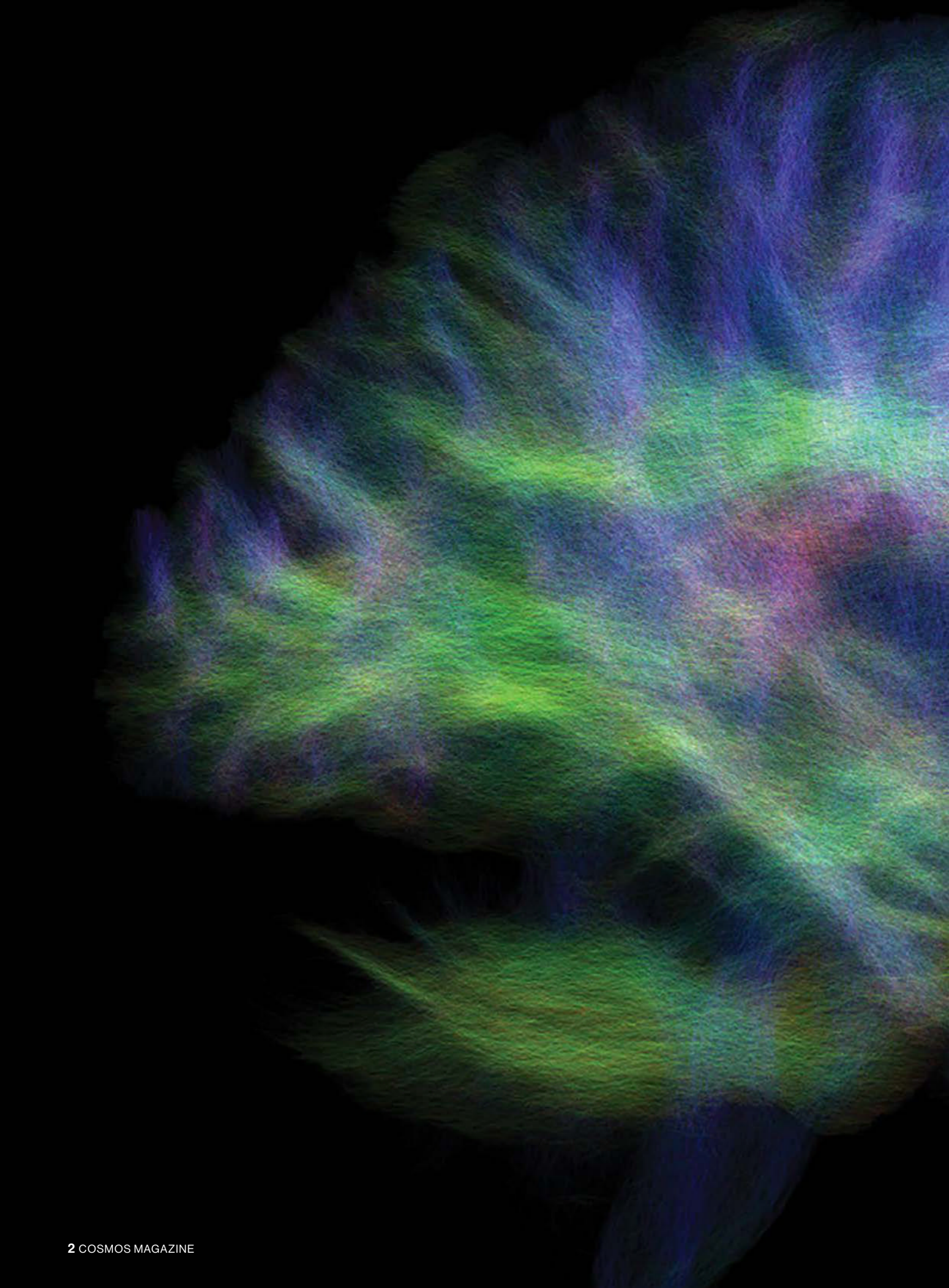

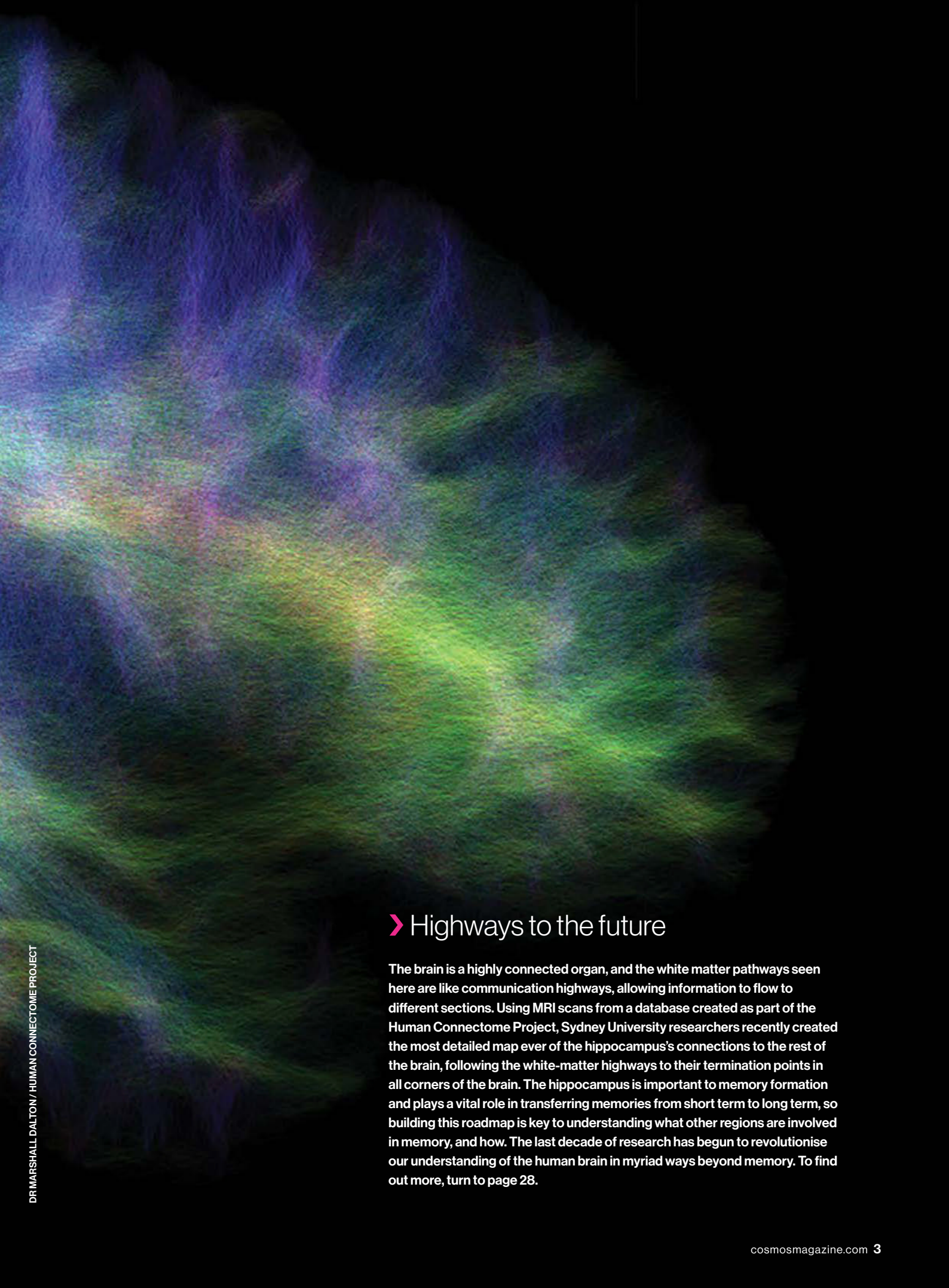

DR MARSHALL DALTON / HUMAN CONNECTOME PROJECT

› Highways to the future

The brain is a highly connected organ, and the white matter pathways seen here are like communication highways, allowing information to flow to different sections. Using MRI scans from a database created as part of the Human Connectome Project, Sydney University researchers recently created the most detailed map ever of the hippocampus's connections to the rest of the brain, following the white-matter highways to their termination points in all corners of the brain. The hippocampus is important to memory formation and plays a vital role in transferring memories from short term to long term, so building this roadmap is key to understanding what other regions are involved in memory, and how. The last decade of research has begun to revolutionise our understanding of the human brain in myriad ways beyond memory. To find out more, turn to page 28.

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FROM TOP: DAVID HANCOCK. JUDITH KUHN, GERMANY, SHORTLIST, OPEN COMPETITION, LANDSCAPE, 2023 SONY WORLD PHOTOGRAPHY AWARDS. NATIONAL ENVIRONMENT RESEARCH COUNCIL.

Making a tribe

WE ARE PREPARING to launch a new initiative that will bring our readers together and create a community that can grow into the future. My Cosmos will put you at the centre of our universe and support our work to bring science to everyone.

My Cosmos is a membership program that will replace our online subscription programs. Subscriptions to the *Cosmos* print magazine will continue, but print subscribers will have the added benefit of free membership to My Cosmos.

We want to build a community that connects with us and with each other. Members of our community will have access to *Cosmos Weekly*: stories that look at the science behind our lives. A range of other benefits will be available soon.

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Sabino del Balso

From: Gail MacCallum, editor

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From the Editors

SERIOUSLY, COULD THERE BE a better time to consider intelligence, both human and artificial? Sorry to reach for the daggy analogue analogy, but: the best time to plant a tree is 20 year ago. Or right now.

At the same time that machine learning – possibly several years ahead of expectations – has booted large language models into both the headlines and hysteria, researchers plumbing the depths of the human brain draw ever closer to really knowing how it works, and why. Editor-at-large Elizabeth Finkel reports on the current state of brain-function investigation, while Richard A. Lovett reports on an astonishing leap in our ability to literally read minds. Something on which everyone seems to agree: AI is the thing that'll make the difference to brain research – and many other fields as well.

What else would have us more, or most, excited than David Hancock's story about the repainting by the Bininj people of a revered spirit ancestor in Western Arnhem Land, in the Northern Territory. This effort – a collaboration between traditional custodians and modern scientists – models a future in which Indigenous Australians' deep knowledge of, and cultural ties to, this land might scale equally as we seek long-term ecological knowledge to respond to the climate crisis.

Elsewhere in the issue, we've returned to our New Ways of Seeing series – supported by funding from the Copyright Agency's cultural fund – as Drew Rooke explores the growing understanding of long-distance bird migration, with particular focus on the surprisingly charismatic bar-tailed godwit. (Trust us: read the article, then break out the binoculars.) Ashley Hay dives into the waters of the southern Great Barrier Reef to witness marine scientists discovering *new species* (in the GBR? Yep – really). And Clare Watson reveals the global fight against dengue fever using Trojan mosquitoes developed in Australia a decade ago. *Wolbachia*-infected mosquitoes are showing amazing success at large scale in protecting against diseases including dengue and Zika, and as is so often the way, embedded in this clever solution, a mystery remains: how?

Thus the great adventure of science continues to step forward, adding answers and new questions as it goes. Join us on the journey.

GAIL MacCALLUM Editor
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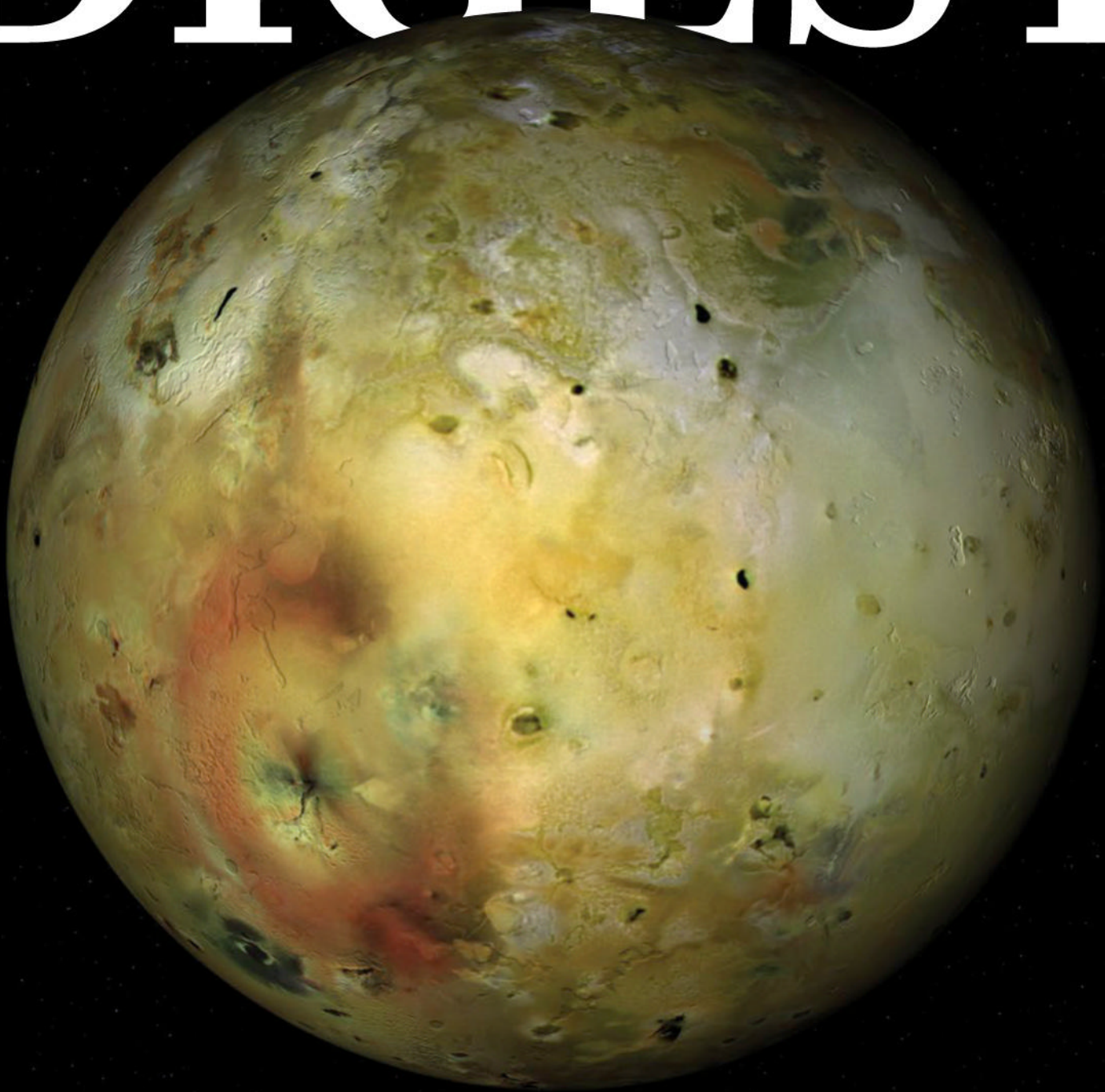

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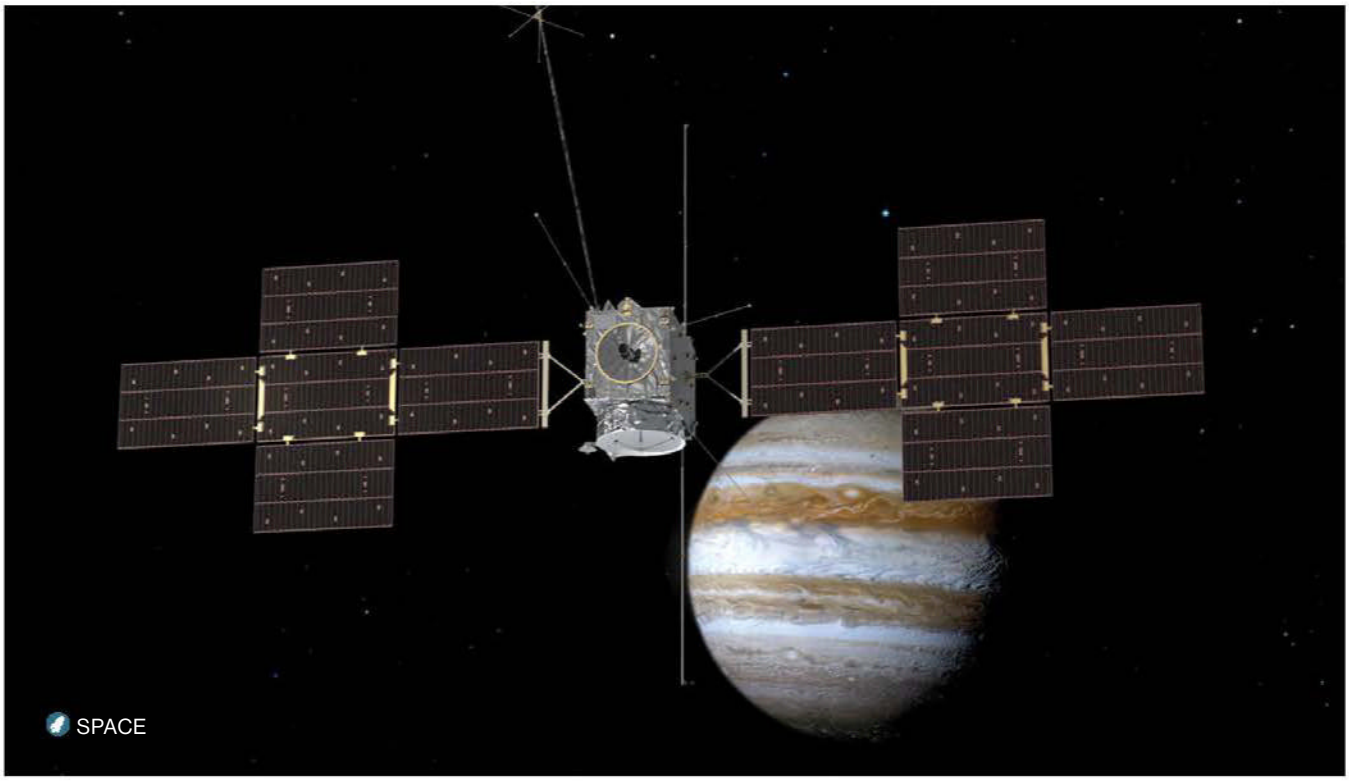
▸ Io, as seen from Voyager.



Europe's JUICE mission is off to Jupiter – here's what you need to know

Eight-year journey to the solar system's biggest planet.

EUROPE'S JUPITER Icy Moons Explorer (JUICE) mission successfully launched on 14 April 2023, headed off to explore some of the Solar System's most mysterious ice worlds.

Over the next decade, JUICE will chart the gas giant and its interactions with three of its four largest moons, which are covered in thick ice sheets. Below these frigid surfaces, scientists expect to find potentially world-covering oceans.

The European Space Agency's mission also hopes to extend our knowledge of planet formation and how it may support the emergence of life.

It's unlikely that JUICE will find even simple lifeforms beneath the ice, but it will investigate the habitability of the moons.

"JUICE…has taken the better part of the past decade to be designed and developed and is now ready," says Alessandro Atzei, JUICE's payload system engineer.

Over 17 days after launch, the spacecraft's solar arrays, probes, antennas and booms were deployed. In total, JUICE is the size of two tennis courts and weighs about as much as an adult elephant.

"It will take quite some time to arrive at Jupiter…in the distant July of '31 and then the real mission will start," Atzei says. "We'll [first] focus on Europa, then we'll go to a high latitude phase which is basically focusing on the polar areas of Jupiter itself."

WHAT'S JUICE GOING TO DO?

Jupiter is the biggest planet in the Solar System – a 142,000-kilometre-wide gaseous world that could fit more than 1,300 Earths inside it. It pulls 92 moons into its orbit, and has a magnetic field 20 times more powerful than our planet's.

JUICE will try to understand how the gas giant's unique properties have influenced the formation of its largest moons as well as the wider planetary system.

The mission will also look at the characteristics of Ganymede, Callisto and Europa, including studying their oceans; mapping the topography, geology and composition of their surfaces; studying the properties of their icy crusts; and looking deep into the moons' interiors.

GANYMEDE

The largest moon in our Solar System, (and around half the size of Earth), Ganymede is believed to possess a saline ocean under the ice, which may cover the entire celestial body. The moon is one of the oldest space bodies in the Solar

CREDIT: ESA/ MEDIALAB.

System, with a geological history stretching back billions of years.

Ganymede also generates its own magnetic field and has a tenuous atmosphere, which are of particular interest to the JUICE mission.

CALLISTO

The second-largest moon orbiting Jupiter, Callisto is a fraction smaller than Mercury and bigger than the dwarf planet Pluto. Callisto is another ancient world that appears to have ceased geological activity at least a billion years ago. Studying it will give scientists an idea of what the space environment around Jupiter might have been like during the early formation of the planet.

EUROPA

Europa's veiny surface is mainly ice, and likely also conceals an underlying liquid ocean. For this reason it has been suggested as a possible home for simple life (and was featured in classic science fiction works like Arthur C. Clarke's *Space Odyssey* series). Scientists also hypothesise that plumes of ocean and ice may erupt from the surface into space.

WHAT ABOUT IO?

Io is the most volcanically active place in the Solar System, with kilometre-high lava plumes driven by gravitational interactions with Jupiter and its neighbouring moons Europa and Ganymede.

Unsurprisingly, Io's volcanic nature keeps it ice-free and for this reason is unlikely to host life; it won't be explored in detail as part of the JUICE mission.

HOW IS JUICE GETTING TO JUPITER?

On 14 April (local time), the JUICE spacecraft blasted into space on board an Ariane 5 rocket from the European Space Agency's spaceport in Kourou, French Guiana. After launch, it will perform a series of flybys of Earth, the Moon and Venus to calibrate its course towards Jupiter. These flybys are imperative to the mission, effectively juicing (pardon the pun) the spacecraft with gravity assistance to slingshot it towards its target planet. These flybys will take place in August 2024 (Earth and Moon), August 2025 (Venus), September 2026 (Earth) and January 2029 (Earth), so JUICE will spend six years simply building up its speed to jet off to its destination.

In July 2031, it will start a three-and-a-half-year tour of Jupiter and its icy moons, before a final tour of Ganymede in December 2034; the mission will end when JUICE smashes into Ganymede's surface in September 2035.

JUICE (above, being prepared for loading onto the Ariane 5 spacecraft) will arrive at Jupiter in 2031 (opposite, artist's impression).

ESA-CNES-ARIANESPACE/ OPTIQUE VIDÉO DU CSG, S MARTIN

CLIMATE

World's ice melting five times faster than in the '90s

Polar ice is melting at an unprecedented rate and accounts for a quarter of all sea level rise.

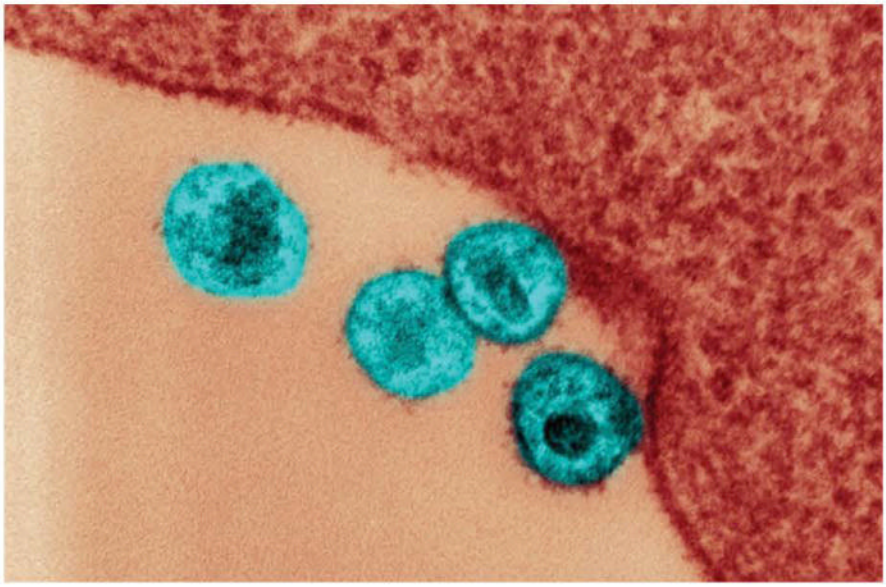
Figures published in *Earth System Science Data* show there has been a five-fold increase in ice melt since the 1990s; seven of the worst years have occurred in the past decade.

The research – by a decade-long international collaboration between dozens of institutions called IMBIE (Ice sheet Mass Balance Intercomparison Exercise) – compiled 50 satellite surveys of Antarctic and Greenland ice sheets between 1992 and 2020.

During that time, more than 7,500 billion tonnes of ice disappeared across both locations, or about 40 Sydney Harbours.

Continuous monitoring of the ice sheets is now required to forecast their behaviour and help plan human adaptation.

Dr Diego Fernandez, head of research and development at the European Space Agency, which co-funds IMBIE, made the grim assessment that polar ice variations "have reached a scale where abrupt changes can no longer be excluded".



MEDICINE

HIV cured in third person after stem cell transplant

The stem cell procedure is risky, but there's mounting evidence that it works.

ANOTHER PATIENT is free from HIV, after a stem cell transplant used to treat leukaemia also suppressed the virus.

The patient, a 53-year-old male, was previously HIV-positive but has had undetectable levels of the virus in his blood for nine years. He stopped using anti-retroviral treatments four years ago and remains healthy; the HIV hasn't resurfaced.

The treatment used – hematopoietic stem cell transplantation, or HSCT – has been successful at suppressing HIV in two other people, referred to as the "London patient" and the "Berlin patient".

This patient, also called the "Düsseldorf patient", was first tentatively announced as cured of HIV in 2019, shortly after stopping anti-retroviral treatments.

With four years' more data, the international team of researchers has now confidently described his long-term remission in a *Nature Medicine* paper.

Like the Berlin and London patients, the Düsseldorf patient had HIV-1: the most common type of HIV, accounting for more than 90% of infections. He was diagnosed with acute myeloid leukaemia in January 2011, and received a stem cell and immune cell transplant from a donor in February 2013, alongside chemotherapy.

Crucially, the stem cells from this donor had a specific property: they're called CR5Δ32/Δ32 hematopoietic stem cells, and they're HIV-resistant.

Dr Ioannis Jason Limnios, from Bond University's Clem Jones Centre for Regenerative Medicine, who was not involved in the research, says it's "exciting progress in the fight against AIDS".

"This study shows that transplanting blood stem cells from an HIV-resistant donor has led to the development of a new, HIV-resistant immune system in an HIV-positive patient."

SPACE

New map shows the cosmos is less "clumpy" than we thought

A new, more accurate map of all the matter in the universe – including both visible matter and the elusive dark matter – has led astronomers to conclude that the universe is not as clumpy as previously thought, adding fuel to the thought that our Standard Model of the universe is incomplete.

Scientists believe that such maps can tell us about the forces that continue to shape the evolution of the cosmos. The new map combines data from two major telescope surveys: the Dark Energy Survey in Chile and the South Pole Telescope in Antarctica. Both utilised gravitational lensing, a phenomenon that sees light bend as it passes by massive objects like galaxies, capturing both regular matter and dark matter.

According to the updated map, the stuff in the universe is more spread out, rather than clustered in certain areas. This adds weight to the longstanding thought that there are forces at work in the cosmos that we are yet to fully grasp, or even completely unknown phenomena at work.

CALLISTA IMAGES / GETTY IMAGES

MEDICINE

Portrait of Beethoven by Joseph Karl Stieler, 1820.

Scientists decode Beethoven's genome

Can these genetic insights tell us what killed him?

DEAFNESS, GASTROINTESTINAL and respiratory issues, rheumatism, alcohol-related liver disorders, lead poisoning: the list of afflictions plaguing the life of composer Ludwig van Beethoven fascinates historians and scientists alike. Now, using his hair samples, researchers have decoded his genome in an effort to learn what really killed him.

Much knowledge of Beethoven's illnesses have been assembled from historic accounts, such as his diaries and letters, but now an international team can say what did – and didn't – play a role in his death in 1827.

Multiple indicators of liver disease unscrambled from his DNA suggest that this likely led to his death. And while an explanation for his deafness remains elusive the researchers behind the investigation are hopeful that more genetic markers in modern-day humans will emerge over time that might point to a culprit in Beethoven's genome.

"Reference data, which are mandatory to interpret individual genomes, are steadily improving," says Cambridge PhD student Tristan Begg, who led the study. "It is therefore possible that Beethoven's genome will reveal hints for the cause of his hearing loss in the future."

Hair samples are generally well-preserved sources of DNA that can be used to analyse genetic information, but the researchers first had to perform some quality control. They cross-referenced eight samples obtained from Beethoven collections across Europe, the UK and US, and found five to be authentic. Three were ruled out.

One of these three was the so-called "Hiller lock", which was previously used to prescribe lead poisoning as a cause of Beethoven's death and afflictions. However, the research team found that the hair actually came from a woman with ancestral ties to modern North African, Middle Eastern and Jewish populations.

"Since we now know that the Hiller lock came from a woman and not Beethoven, none of the earlier analyses based solely on that lock apply to Beethoven," says Begg.

"Future studies to test for lead, opiates and mercury must be based on authenticated samples."

TECHNOLOGY

Could asking GPT-3 replace human surveys in political polling?

RESEARCHERS FROM Brigham Young University in the US have shown that the large language model GPT-3 can accurately reflect political views and voting intentions for specific groups of people.

They set up GPT-3 to mimic demographic populations based on characteristics like race, age, ideology and religion.

They then asked the AI for its voting preferences in the 2012, 2016 and 2020 US presidential elections.

Comparing the results with the American National Election Studies human database, there was high correspondence between the AI and humans voting intentions.

The study notes GPT-3 can closely represent public opinion in the United States, suggesting it could be used in social science research, or to test political slogans.

But while there would be cost benefits, the researchers note the tool has "dangerous potential" if used to target specific human groups with misinformation, manipulation and fraud.

IAN SHRINER, BENJAMIN FREEMAN

BEETHOVEN-HAUS BONN.

NATURE

Found you! Five new frog species in Papua New Guinea described

And their tadpoles aren't where you'd expect.

FIVE FROG species from Papua New Guinea that exhibit characteristics rarely witnessed in other tree frogs have been described by scientists for the first time.

While tree frogs typically lay their eggs directly into water, the newly described species of the genus *Litoria* might all use structures like trees and rock faces to deposit their offspring. This may have evolved to protect tadpoles from predators in water bodies below.

Arboreal laying was only confirmed in the slender spotted tree frog (*Litoria gracilis*) and the Crater Mountain treehole frog (*L. naispela*), though the researchers suspect the other three – the Darai Plateau tree frog (*L. daraiensis*), red-bellied tree frog (*L. haematogaster*) and Lisa's tree frog (*L. lisae*) – exhibit the behaviour too.

The Crater Mountain treehole frog appears to also share unique reproductive strategies with other, less closely related frog species that glue their eggs in sacs above treeholes. When the eggs hatch, the tadpoles drop into water pooled in the treehole below.

"[This] really suggests that it's a very good strategy to keep your eggs and tadpoles out of the water for as long as possible," says lead researcher Dr Steve Richards, from the South Australian Museum. "The rationale for that is there's a lot of predators in water."

▲ Clockwise: Red-bellied tree frog (*Litoria haematogaster*), slender spotted tree frog (*Litoria gracilis*), Darai Plateau tree frog (*Litoria daraiensis*), Lisa's tree frog (*Litoria lisae*). Centre: Crater Mountain treehole frog (*Litoria naispela*).

Others, like Lisa's tree frog, might attach their egg sacs to the walls of limestone sinkholes. While the researchers weren't able to document this taking place, they did hear the calls of these frogs from within these structures.

"There is a suspicion that they certainly have an unusual reproductive behaviour," says Richards.

"They call from down in these limestone crevices and sinkholes... we don't know, but it's certainly unlikely to be on trees or leaves like the other ones, but maybe some other form of arboreal egg laying where they are putting them outside the water."

Like many organisms, physical characteristics are used to distinguish species from one another. In the field, Richards records frog calls and appearances of frog species to build the case for describing a new species.

In the lab, his colleague from Queensland Museum, Dr Paul Oliver, analysed the genetic profiles of the specimens, seeking out evidence of genetic divergence. As levels of genetic divergence go up, Oliver explains, so too does "the probability that you're dealing with something that's a separate species or what you might say is on a separate evolutionary trajectory".

New Guinea is home to one of the most diverse concentrations of frog species in the world: it has 7% of global frog species in just 0.7% of the world's land area.

With this in mind, it's likely that more species will continue to be discovered.

"Our estimate, at the moment is of 700 species [in New Guinea]," Oliver says. "By comparison Australia's got about 250.

"But what's cool is that most of those species in New Guinea, we just know nothing about them. It's only just now that we're starting to document these behaviours."

STEVE RICHARDS

SPACE

Lunar water is being stored in glass beads

The Moon's water could be stored in glass beads created by meteorite impacts, according to new research in *Nature Geoscience*.

Surface scans and analysis of Moon rocks have confirmed that there's a small amount of water on the Moon. But where is it stored? Some regularly gets lost to space, which means there must be a hydrated reservoir somewhere to buffer that loss.

Researchers led by the Chinese Academy of Sciences examined lunar soils brought back by Chang'e-5. They looked specifically at impact glass beads in the soils, which are created when asteroids hit the lunar surface and cause molten material from the Moon's interior to spew out.

These glass beads are very high in water content, by Moon standards, with up to 0.002 grams of water per gram of bead.

Extrapolating this out, the researchers say these glass beads could account for between 3.0×10^{11} and 2.7×10^{14} kg of water on the Moon's surface – that is, between about one and 500 Sydney Harbours.

The isotopes in the water show it likely comes from the solar wind.

PETER SCHOUTEN (SUPPLIED).

PALAEONTOLOGY

Ancient wombat cousin sheds light on how marsupials evolved

The animal is described as a cross between wombats and the extinct marsupial lion.

REMAINS OF a previously unknown ancient wombat-like marsupial have been discovered in central Australia. Called *Mukupirna fortidentata*, the animal is thought to share a common ancestor with modern wombats.

Flinders University palaeontologists uncovered 35 different *Mukupirna* specimens after digging for more than 2,000 hours in the hard limestone of Pwerte Marnte Marnte, about 75 kilometres south of Alice Springs in the NT. The results are published in *Alcheringa: An Australasian Journal of Palaeontology*.

The fossils date to 25 million years ago, during the late Oligocene, when Australia's centre would have looked very different: wetter and covered in forest, with vast freshwater lakes home to flamingos and dolphins.

"They are a bit of an evolutionary intermediate between wombats and their more koala-like relatives," says Flinders PhD candidate Arthur Crichton.

"It's not really correct to say that Mukupirna is an ancestral wombat either. It seems to have gone off on its own evolutionary tangent that is very much unique in the context of marsupial evolution."

By measuring its teeth and limbs, the scientists worked out that *M. fortidentata* would have weighed up to 50 kilograms. This would have made it one of the largest marsupials alive at the time.

Its molars were similar to those of some monkeys, like macaques. But its front teeth were huge and spike-shaped, like a rodent.

"These are some of the oldest marsupials known from Australia and are really important for understanding how our iconic marsupials came to be," Crichton says.

TECHNOLOGY

Scientists look at how single-celled organisms might help build better AI

Harnessing nature's computational power.

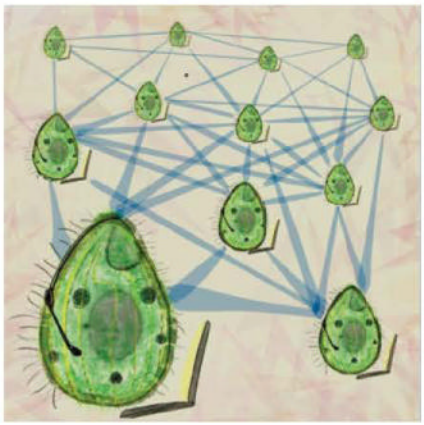
NETWORKS IN natural ecosystems can be used to improve information processing systems in artificial intelligence (AI), according to new research at Japan's Kyoto University.

We're surrounded by such networks, from the food web to complex underground communication networks among plants and fungi. But what's that got to do with a machine-learning algorithm?

Computers are essentially information processors. They do this through algorithms – taking information in and spitting it back out according to what the algorithm directs the computer's software to do.

It should come as no surprise that, as with a great many things (flying or magnetic navigation, for example), nature got there first.

Researchers at Kyoto University have now demonstrated the computational power of ecosystems, and they believe it will help in rapidly developing AI technologies.



The information processing capacity of natural ecosystem gives researchers clues about how ecosystem dynamics are maintained.

In their simulations, the scientists showed that ecological networks, like those between predator and prey organisms, can process information efficiently. This makes them strong candidates for use as computational resources.

The approach has been dubbed "ecological reservoir computing", according to ecologist Masayuki Ushio, who is now a principal investigator at the Hong Kong University of Science and Technology.

Two types of ecological network were studied to see if they possess computational power.

One was artificial. Called *in silico* ecological reservoir computing, it models hypothetical ecosystem dynamics to simulate the response of the system.

The other, called real-time ecological reservoir computing, measured the population dynamics of the single-celled organism *Tetrahymena thermophila*. For this test, the researchers adjusted the temperature of the environment in which the organisms were living (the temperature being the input data) and counted the number of cells present – the output data.

The study confirmed that the single-celled organism population was able to make predictions into the near future to affect the overall ecology (number of cells).

"Our new computing method might lead to the invention of novel types of computers," says Ushio. "Also, in developing a way to measure the information processing capacity of a natural ecosystem, we may find clues to how ecosystem dynamics are maintained."

BIOLOGY

Sugar, spice and the origin of life: new theory for the first sugars

LIVING THINGS are made of complex organic molecules – but where did those come from?

Origin-of-life chemists have a suite of theories for the origins of amino acids and nucleobases. But sugars – a key part of DNA and RNA – are less well understood. It's commonly thought that they may have started with a compound called formaldehyde (CH_2O).

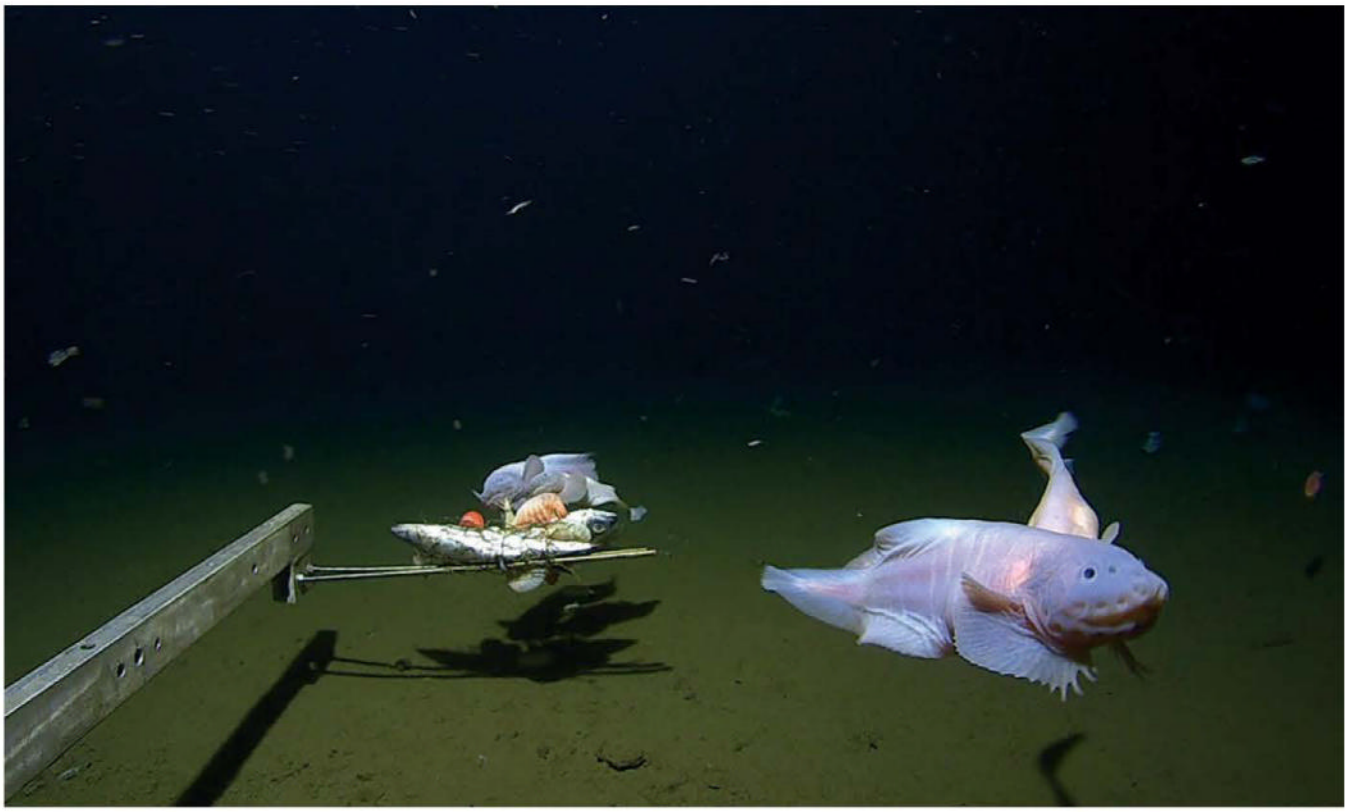
A new theory, published in *Chem*, thinks glyoxylate ($C_2HO_3^-$) is the more likely culprit.

"The formaldehyde reactions...have uncontrolled side reactions and other drawbacks due to formaldehyde's high reactivity under the envisioned early-Earth conditions," says Charles Liotta, from the Georgia Institute of Technology.

Instead, the glyoxylose reaction first reacts with itself, then with its own by-products in a chain until they become complex enough to form sugars.

Next step: show that this reaction works in a laboratory.

KYOTOU/JAKE TOBIYAMA.



NATURE

Marine scientists have recorded fish at the deepest ever level

Japanese and Australian teams set new record for deep-sea fish photography.

SCIENTISTS HAVE delved eight kilometres below the ocean's surface to film a fish, and set new records in the process.

While exploring the Japan, Izu-Ogasawara and Ryukyu trenches as part of a decade-long study into the world's deep sea fish populations, teams from the University of Western Australia and the Tokyo University of Marine Science and Technology spotted a snailfish (genus *Pseudoliparis*) cruising at a depth of 8,366 metres.

This is the deepest recording of a fish yet taken by humans.

Pseudoliparis are a genus first described midway through last century, and known to inhabit the furthest depths of the Pacific Ocean's deep trenches. They are ray-finned fishes and part of the same animal order as lionfish.

The records weren't over, however, with the study team trapping two *Pseudoliparis belyaevi* at 8,002m – a record catch depth for this species.

"It is not necessarily that they are living at 8,336m but rather we have enough information on this environment to have predicted that these trenches would be where the deepest fish would be," says the study's chief scientist, Alan Jamieson, founder of the Minderoo-UWA Deep Sea Research Centre.

"Until this expedition, no one had ever seen nor collected a single fish from this entire trench.

▲ The snailfish live from 7500–8200m in the Izu-Ogasawara Trench.

"We have spent over 15 years researching these deep snailfish; there is so much more to them than simply the depth, but the maximum depth they can survive is truly astonishing.

"In other trenches such as the Mariana Trench, we were finding them at increasingly deeper depths just creeping over that 8,000m mark in fewer and fewer numbers, but around Japan they are really quite abundant."

UNIVERSITY OF WESTERN AUSTRALIA

Focus: Future transport

1 **Researchers have developed the first algorithm to help autonomous vehicles make ethical choices from thousands of possible behaviours, and all in a fraction of a second.**

2 Vehicle pollution doesn't just come out of a car's exhaust – a new study found that cancer-causing compounds are also found in that "new car" smell.

3 We need to rethink allocated car spaces, according to a new study that found a third of apartments in Sydney, Melbourne and Perth have either too much or not enough car parking.

4 **By analysing 30 global studies on aggressive drivers, UK researchers determined that road ragers make about 2.5 times more mistakes than other drivers, from collisions to ignoring stop signs to speeding.**

5 Regional Australians are reluctant to plug into the electric-car culture, according to a new paper, even though they could benefit most, given high fuel costs and long-distance travel.

6 **A new report suggests that air taxis are likely within a decade, and not just for the rich – trips could cost about as much as an Uber.**

www.cosmosmagazine.com/ 01 technology/who-should-the-autonomous-vehicle-kill-new-solution-to-ethical-dilemma/
02 health/new-car-smell-not-so-sweet-for-taxi-and-uber-drivers/ 03 people/time-to-park-allocated-car-spaces/
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WISK AERO

PALAEONTOLOGY

Ancient platypus cousin lived alongside dinosaurs

An ancient platypus relative found in Argentina calls into question when and where this weird egg-laying clade of mammals evolved.

Echidnas and platypuses are the only modern-day monotremes, endemic to Australia and neighbouring islands. But more than 30 years ago, a 62-million-year-old tooth from an ancient platypus, *Monotrematum sudamericanum*,was unearthed in Patagonia, Argentina.

Now, a second lower molar fossil has been found of another ancient platypus cousin, named *Patagorhynchus pascuali*. It lived 70 million years ago in the Late Cretaceous, when dinosaurs still roamed the Earth. In the past, it was assumed that monotremes had only dispersed from their origin in what is now Australia after the extinction of the non-avian dinosaurs 66 million years ago.

This discovery shows that monotremes were already spread across southern South America, Australia and Antarctica.

The find is described in a paper published in *Communications Biology*.

(PLATYPUS) SANTIAGO MINER (LABORATORIO DE ANATOMÍA COMPARADA Y EVOLUCIÓN DE LOS VERTEBRADOS). (CHARLES) PA IMAGES/GETTY IMAGES. (SKY PORTAL) EPOXYDUDE/GETTY IMAGES.

Guess the object

King of...what?

Before the pomp and circumstance of coronation, a younger Charles paid a visit to a newly opened institution with lofty and international goals. While there, he had a chat to scientists who worked with this bulky research tool. It's been around for at least 50 years and is still in use today, especially since new data analysis techniques are making it even more powerful. Plus, what it tells us is getting more and more relevant.

We know you can Google it, but where's the fun in that? Tell us what you think it is. The correct answer – and/or the most creative – will be published in our next issue. Send your hunches to contribute@cosmosmagazine.com

Sky portal

Many astute readers pinpointed last issue's object: "It's a cloud chamber for capturing evidence of invisible subatomic particles," Pete said succinctly. Invented in 1911 by Scottish physicist Charles Thomson Rees Wilson (earning him a Nobel prize), cloud chambers contain a supersaturated vapour. As charged particles zip through it, they ionise the vapour and leave tracks. Reader Sabino Del Balso noted that the chambers were key to early particle physics; for example, cosmic ray tracks revealed fundamental particles like the positron and muon. Delightfully, Sarah Standish wrote that the school where she works has one: "We had some spare CO_2 last year and set it up to demonstrate the trails of alpha and beta particles to the science teachers."

CHEMISTRY

Iridescent, plant-based coatings that cool buildings – and the Earth

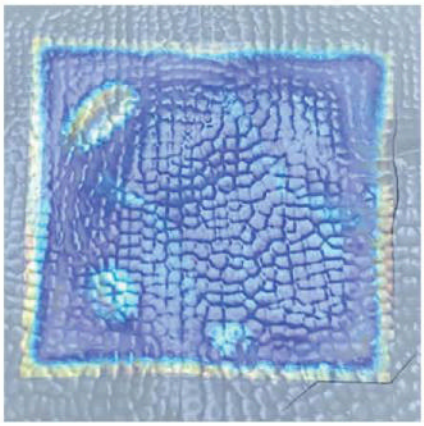
Researchers create a colourful solution to urban heat.

CHEMISTS HAVE made an iridescent, plant-based film that gets cooler in sunlight. It comes in a range of shining colours and could one day coat buildings and cars, reducing the need for air conditioning.

The film exhibits a smart property: called passive daytime radiative cooling (PDRC), it doesn't absorb much light, and it radiates heat out at a wavelength that escapes the atmosphere.

"To make materials that remain cooler than the air around them during the day, you need something that reflects a lot of solar light and doesn't absorb it, which would transform energy from the light into heat," explains principal investigator Silvia Vignolini, a chemist at the University of Cambridge, UK.

"There are only a few materials that have this property, and adding colour pigments would typically undo their cooling effects."



This film is made from two layers of plant-based cellulose materials, and cools down when it's in the sun. It can be tuned to different colours and textures.

Colour usually comes from a pigment that absorbs some sunlight: a green leaf absorbs red and blue light, for instance, while reflecting green.

For something to reflect all sunlight back, it usually has to be white. But colour can come from other properties: for examples, tiny structures inside a substance can bounce the light around until it comes out in a different hue. This structural colour often produces shining and iridescent results, like in beetles.

Vignolini and colleagues figured out a way to create the effect with cellulose, which is one of the few naturally occurring materials known to be capable of forming PDRC materials. Their film is made from cellulose nanocrystals (CNC): tiny particles about the same size as individual wavelengths of light.

These films can be manipulated to look red, green, or blue, but they're quite brittle. The researchers have figured out how to attach the films to ethyl cellulose: a more flexible white material.

When combined, the researchers had a flexible, colourful film 4°C cooler than the ambient temperature during the day.

They've also figured out how to make the films glittery and textured, so they could be adapted to any architectural style. The films should be easy to manufacture metres at a time, and cellulose is a cheap feedstock.

But before you can coat your car or house with them, the researchers want to see if they can introduce more functions: CNCs can be sensitive to pollutants, so they're exploring whether they can build smoke or smog detectors into their films.

NATURE

Modelling suggests world population could peak lower, sooner

Global population could peak by 2050, in a prediction released by the Global Challenges Foundation in Stockholm, based on a model called Earth4All. It considers two economic pathways: one under current economic growth scenarios where the world's poorest nations emerge from extreme poverty, resulting in a population peak of 8.8 billion by 2050, declining to 7.3 billion by the end of the century.

The second, which assumes massive investments in poverty reduction, food and energy security, and gender equity, sees a peak of 8.5 billion by 2040, and six billion by century's end.

"Governments in low-income countries must commit fully to pursuing economic development based on large investments in education, rather than economic growth driven solely by natural resources extraction," the researchers say.

The United Nations has previously forecast a peak of 10.4 billion by 2100.

QINGCHEN SHEN

Australian Mammal of the Year 2023

Have a say in choosing our annual mammal superstar.

GET READY FOR your favourite critters to go head-to-head for the title of Australian Mammal of the Year, because the *Cosmos* competition is back again for 2023. We think of them as fluffy, but don't forget the furred, the finned and the flying – like the southern bent-wing bat who took out last year's prize. With more than 350 other mammals native to this continent, who will be the people's choice this year?

In 2023, we're shaking things up to keep you on your toes (or claws, or flippers). Instead of separating the mammals by category such as the Rollicking Rodents or Beloved Burrowers, we're organising them by ecosystem. Over the next couple of months on *Cosmos* online, we'll delve into the many complex, interdependent webs of life on this vastly diverse continent, and explore how they hang together. After all, it's all very well to champion the southern bent-wing bat, but where would they be without their foraging habitat, their home caves, or the moths that make up the bulk of their diet?

We'll announce the 2023 winner in the next issue of the magazine, but you'll want to get involved before then – finally, it's an election to get excited about!

TO READ MORE ABOUT OUR AMAZING MAMMALS, LEARN ABOUT OUR COUNTRY'S ECOSYSTEMS AND VOTE FOR YOUR FAVOURITES IN 2023, VISIT COSMOSMAGAZINE.COM/AMOTY

Top 10 from 2022:

1. Southern bent-wing bat (*Miniopterus orianae bassanii*)
The southern bent-wing bat was taken under the wing of its south-western Victorian community, and with a groundswell of support was named our inaugural Mammal of the Year.

2. Dingo (*Canis dingo* or *Canis familiaris*)
Australia's charismatic but controversial native dog took out the top spot in the Rock Stars category in a landslide, with a 35% of the vote.

3. Mountain pygmy possum (*Burramys parvus*)
A strong contender, this highly endangered furball held on to make the final three, winning legions of fans in the process.

4. Rakali or Australian water rat (*Hydromys chrysogaster*)
With strong social media support, this urban survivor and Rollicking Rodent winner polled strongly deep into the finals.

5. Gilbert's potoroo (*Potorous gilbertii*)
This beautiful little fungus eater pipped the quokka to leap into the top 10.

6. Platypus (*Ornithorhynchus anatinus*)
An icon that made the top 10 as a wildcard: the highest-voted mammal outside of the winners across all categories.

7. Dugong (*Dugong dugon*)
The darling dugong started and stayed ahead in the Marine Mammals, easily outpacing all comers.

8. Eastern barred bandicoot (*Perameles gunnii*)
Perhaps the most unexpected takeover of the poll, the eastern barred bandicoot secured #1 position in Beloved Burrowers in final days, tipping out the previously unshakeable greater bilby.

9. Northern quoll (*Dasyurus hallucatus*)
In a truly tight race between the Delightful Dasyurids, the northern quoll just managed to pull ahead of the runner-up (the eastern quoll).

10. Southern brown bandicoot (*Isoodon obesulus*)
Caught up in that bandicoot bandwagon, the SBB dashed into second place in the Beloved Burrowers, and the second-most votes across all of the categories.

ENVIRONMENT

How AI can be used to track pollinators in strawberry crops

AI-driven video analysis helps farmers remotely understand how their crops are pollinated by insects.

DEEP LEARNING algorithms are being applied to digital video to identify four different pollinator species working in a strawberry farm, and to plot the insects' visits to flowers.

A team from Monash University, led by postdoctoral researcher Malika Ratnayake, has developed a proof of concept for a system that automatically reports which pollinators visit a crop, how often they visit and from what direction – potentially superseding the expensive and time-consuming manual methods of pollinator assessment.

The system has been tested on a commercial strawberry farm at Boneo, Victoria; the results were recently published in the *International Journal of Computer Vision*.

Malika Ratnayake sets up cameras to record pollinator species visiting strawberry flowers.

Greenlight PROJECT
SUPPORTED BY THE WALKLEY FOUNDATION AND META

More than a third of the world's food production from crops relies on animal pollination. Each crop has different requirements around the optimal number of visits a flower needs from insect pollinators to maximise fruit yield and quality. But while there has never been greater need for efficient pollination, climate change is affecting the pollinators' ability to do their job – partly through direct effects on the individual insects, and partly because shifting climate zones are bringing new insect species into conflict.

"Currently, there are no automated or efficient ways to monitor pollinator performance and use the information to manage pollinator populations in a timely manner," Ratnayake says.

"Our system can record insect movement data in different parts of a farm, automatically count insects and insect-flower visits in each area, and compare the contribution of different insect types to crop pollination.

"With the data in hand, growers can see whether they need to shift bee hives to better support areas of their crop, or raise the side walls of a greenhouse to allow better access to insects from a certain direction."

Ratnayake is also working with the German Centre for Integrative Biodiversity Research to adopt the technology for insect biodiversity monitoring.

The prototype system used nine camera trap modules built from low-cost Raspberry Pi cameras and Raspberry Pi computing boards to capture video at 1920 × 1080 resolution, at 30 frames per second; lower quality would not have provided enough resolution for analysis.

The footage was then passed through an automatic algorithm, largely adapted from two algorithms developed by Ratnayake – one to track a single insect through occlusions by foliage and changing backgrounds of an outdoor environment, and an evolved version that can track multiple insects simultaneously.

The latest deep learning model distinguishes between four insect species, and forecasts likely flight trajectories for each species, to build a picture of how each species visits the crop's flowers. The model also tracked flower movements.

The team are now are working on expanding the developed system to an end-to-end fully-automated real-time "precision pollination" framework.

Building a commercial version would require new capabilities with increased computing efficiency, including developing their algorithms to deal with "3D" plants like blueberry bushes, and to add more pollinator species.

ASADUZ ZAMAN.

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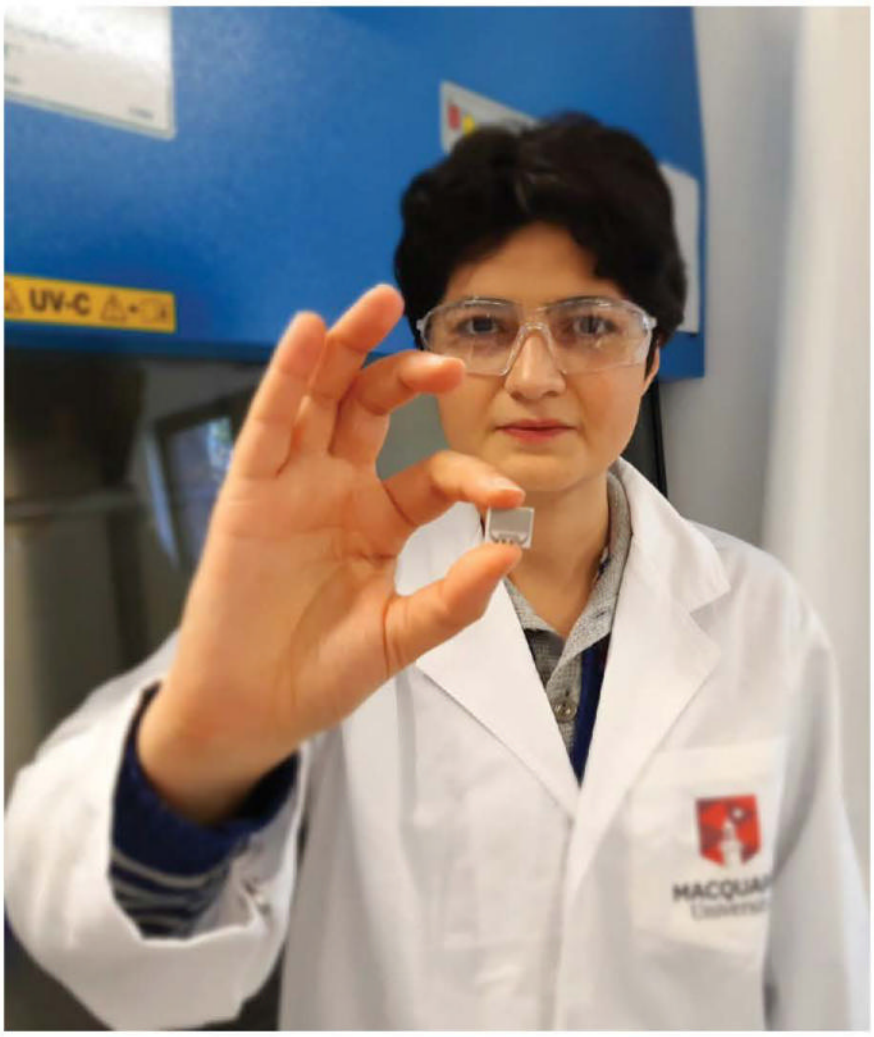
COSMOS AUS

The next TINY thing

When you enter the nanoscale, it's a different world – with enormous possibilities.

By Noushin Nasiri



When I started my PhD, I didn't have a background in nanotechnology, and I really struggled to grasp the concepts that exist at nanoscale.

I remember talking to my supervisor about one of the concepts that contradicted the whole understanding that I had learned from seven years of study of material science and engineering technology.

There was a rubbish bin outside of his office window, and he said to me, "Could you please just go outside to that bin and vomit everything you've learnt into it? It doesn't help you. What you've learned is the knowledge of the micro, but I want you to learn the knowledge of atoms and molecules. And these two scales do not work together in parallel."

The best example is gravity, which we learn from a very young age impacts everything – from the rain that falls, to the movement of the stars and planets.

Yet gravity doesn't exist at all in the nanoscale. When you work in atoms and molecules, you are dealing with a very new set of rules, and a new bunch of forces that are impacting your nano particles.

We usually don't even consider gravity at all in our calculations: the chance of that matter particle being hit by another molecule, and then being moved in the other direction, is much greater. Forces like electromagnetism and Brownian motion – and even the tiny magnetic force between two charged particles – are far more likely to change behaviour.

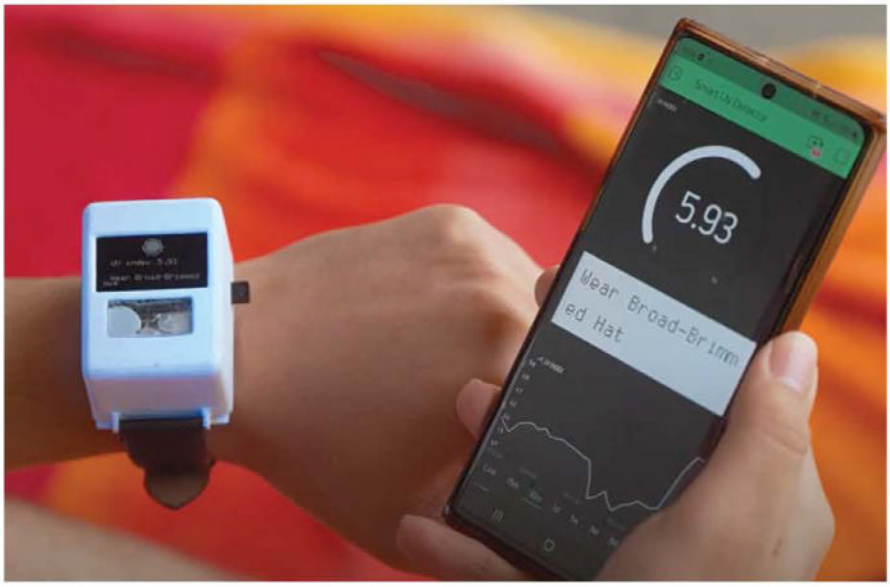
Nano, remember, means one billionth. One nanometre is one billionth of a metre. Very, very, very tiny.

The irony here is that because we work on such a very small size, we need to use huge pieces of equipment. We have to create a controlled environment inside that equipment to manipulate the movement of molecules. The challenge for us is to use nanotechnology to bring down the size of this kind of infrastructure.

My PhD project was a UV sensor that is so tiny that you can have it on your sunglasses or clip it onto your clothing to measure how much UV is absorbed by your skin.

I wanted to work on something that would benefit society, and had read that Australia has the highest mortality rate of melanoma in the world – and only 4% is

MACQUARIE UNIVERSITY X3



Left: This wearable device is currently a prototype, but one day it could save your life. The SunWatch contains a fingernail-sized nanosensor that detects UV rays and alerts you when you've had too much sun exposure. It even takes into account your skin type to deliver personalised, precise advice.

genetic, meaning 96% can be prevented by reducing UV exposure. But you can't see UV and you can't feel UV, which makes it very difficult to estimate how much you've absorbed through your skin.

So I thought, what if we can create a device that can just talk to the end user and tell them, "Hey, you've absorbed 80% of the recommended exposure. Time to take cover."

The first version was a little bit chunky, like a watch, but over time it has become as small as a Fitbit. Right now, my students are working on making it even smaller, like a five-cent coin.

When I was researching these nanoscale sensors, I realised that some are also sensitive to gases. This realisation opened a new door and I began work on a different type of project. What if we can make a tiny sensor that is sensitive to particular gases? It can have many different applications.

I chose to work on the detection of acetone in our breath, because acetone is a biomarker for diabetes – the level of glucose in the blood. People living with diabetes have to prick their fingers for blood four times a day to get that measurement. It's an invasive test, and even adults can mentally struggle to accept that they have to do the test again and again. For kids, it's even more challenging and painful.

So I built a tiny, spongy, super-porous sensor. Even though the acetone trace is very, very low, we can still detect the disease by analysing human breath.

> If we can detect parts per trillion with devices built at nanoscale, that would be the next big thing.

This is not my idea – everyone knew it. And we already have machines that can make this measurement – but they are huge infrastructure. The challenge has been to do it in real time, with a tiny device. What if the end user could just pick up the device, breathe onto the sensor and see the level of glucose in their blood?

A normal level of acetone in the breath for a non-diabetic is one part per million. But if you have two parts per million, you are diabetic. So it's not enough for the sensor to be sensitive to parts per million. It should be sensitive to parts per *billion*.

I now have a sensor that can detect 10 parts per billion.

To improve this even further, we can look to nature, because dogs and bees can detect parts per *trillion*. Researchers are still struggling to understand how these creatures do this, but they've been digging into how they smell, how they analyse and how they can be trained. We already have very good information, and I used some of it in building my sensor.

But if we can detect parts per trillion with devices built at nanoscale, that would be the next big thing. It would open up the potential to create sensors for virtually every disease – especially many cancers. Medical doctors have already published papers that demonstrate that the biomarkers for around 30 diseases can be found in human breath. We know they're there, but often in parts per billion – so we need to be able to measure parts per trillion.

If I can push these sensors to parts per trillion... That's my passion, my motivation. We're not there yet, but we are making great advances.

DR NOUSHIN NASIRI is Head of the NanoTech Laboratory at Macquarie University.

Currents of life

To grasp the urgency of the climate emergency, we need a deep understanding of our ocean's depths. By **Trevor McDougall AC**

Above: Each robotic instrument in Argo's fleet spends most of its life below the surface. Its mission: to provide a regular profile of the top 2,000 metres of ocean in its location, including pressure, temperature and salinity.

Oceanographers began going to sea in ships about 200 years ago, with maybe one or two expeditions per year from the UK. By a quarter of a century ago, 15–20 ships around the world were doing the work.

Fortunately, in the last 15 years global oceanography has been revolutionised by a brand-new technology called Argo. This is a series of about 3,800 floats deployed across the world's oceans to take vertical measurements every 10 days, by sinking to a depth of 2,000 metres then coming to the surface to transmit the information they've gathered to satellites. In the Southern Ocean we're now getting more data every year from this new technology than we did in the previous century.

We also now have specialised satellites – some measure and map the wind stress on the ocean, while others measure the height of the sea surface accurate to within a millimetre or two, which gives us information about global surface currents.

These technologies help us understand so much more about the ocean through observations. Ever-faster, ever-larger supercomputers then allow us to model the ocean with better and better resolution.

If it wasn't for the atmosphere and the ocean moving and thus transporting heat, the temperature differences on Earth would

NATIONAL OCEAN AND ATMOSPHERIC ADMINISTRATION

be extreme. This heat transport is the basic thing we are all studying when investigating climate variability and climate change.

People understand that the El Niño Southern Ocean phenomenon affects our weather patterns, influencing climate variations on a timescale of between two and seven years. El Niño and oscillations like the Indian Ocean Dipole involve a coupled instability between the atmosphere and ocean, down to 200–300 metres in depth.

But with climate change happening over decades and centuries, you've got to look deeper, down to thousands of metres. And at these depths, under that sort of pressure, the mathematics describing the mechanisms of heat transfer is very complex – which is where my work comes in.

For example, if you're 1,000 or 3,000 metres deep, it's very hard to get the ocean to mix vertically. The rate of mixing horizontally – whether it's of temperature, salinity, oxygen, etc – is about a factor of 10 million times stronger than vertically. You can think of it as a party drink with layers of red, yellow and green alcohol of various densities. In the ocean it's difficult to get those coloured layers to mix. If you put a little blob of dye at those depths and come back a year later, it will have dispersed vertically by no more than 50 metres – but moved horizontally around half an ocean basin, across thousands of kilometres.

It's really important in models and in interpreting observations to be able to determine the direction of this strong lateral mixing. But it's complex, because the density in the ocean depends not only on temperature and salinity but also on pressure, so it's a bit of a mathematical puzzle.

What I've done is to bring some rigour to these calculations. I was able to produce an algorithm that oceanographers now use to label observations with a density variable called neutral density. (There are various types of density, all with their complications.) This algorithm has become very popular – basically, anyone who studies the ocean below a few hundred metres in depth uses this variable.

There are still improvements to make and challenges to overcome, but challenges have been part and parcel of my career.

I came to oceanography through engineering – in particular, through the fluid mechanics aspect of engineering. But I faced one large obstacle early on.

I was brought up in a closed religious cult, the Exclusive Brethren. Science had no place in its culture at all – and even listening to the radio or watching TV was outlawed.

I was brought up in a closed religious cult, the Exclusive Brethren. This cult forbade social contact with anyone outside their reclusive membership. Science had no place in its culture at all – and even listening to the radio or watching TV was outlawed.

Slowly at first, and then growing into an absolute conviction, I decided that this strange religious cult made no sense. I couldn't imagine spending my life in it. The sect was not encouraging of my interest in science at all. In fact, I was the last person in the whole world in the cult to be allowed to go to university. Every Sunday people preached at me saying that I shouldn't be studying. So, in the last term of my fourth year at Adelaide University, I faced my parents and told them that I couldn't remain in the sect that had directed their whole lives.

Such a life-changing decision was incredibly difficult to make. Looking back, I don't know how I did it. But I was aware of an inconsistency in what the global leader of the church was saying publicly and what he had told myself and my father. This inconsistency made me question the whole religion, and I started to reason: what's the chance of these few thousand people being the only correct people in the world? I knew that if I told my parents I didn't want to be part of their religion anymore, I'd never see them again. And that's how it worked out. I never saw my sisters or brother again.

I was allowed back once for my father's funeral. Some years later when my mother died, I was not informed, and found out by accident some six months later. They well and truly drew up the drawbridge; if I wasn't part of the Exclusive Brethren, then I was worse than nobody. But I knew that was how it was going to be. And so I just moved on.

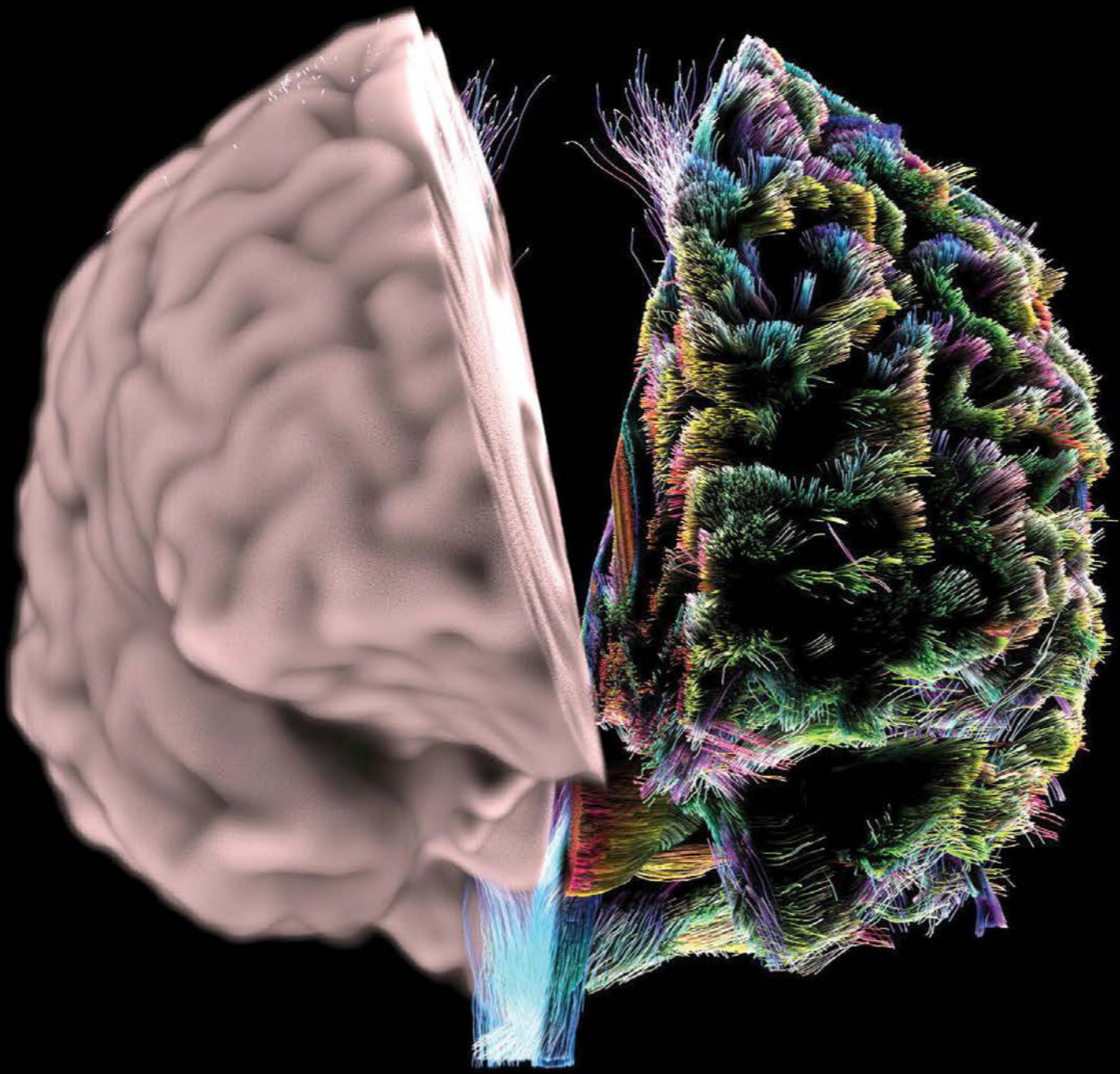
Having decided that I could not be true to myself while remaining in this religious cult, I felt empowered and a whole world of opportunities opened up. I started a new life at age 21. Shortly after, I found myself in Cambridge, UK, slowly purging years of religious brainwashing from my head and designing from the ground up who Trevor McDougall was going to be.

Looking forward from today, the next big challenge for me is take on more of the theoretical mathematical concepts that have been accepted by theoretical oceanographers, and develop them into practical tools that can be used by all observational oceanographers.

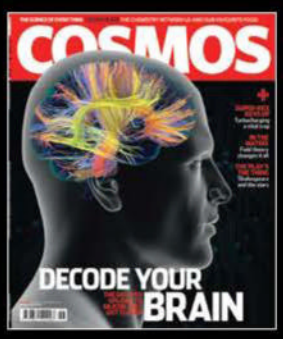
A lot of data is streaming in from these new instruments, but how do we analyse it to determine, for instance, the rate of mixing in the vertical direction? This is a whole subject in itself, and it relies on accurate practical software tools that I'm now developing.

Discovering new things in science is satisfying work, but climate change adds another element to our work. Every year the predictions of our changing climate become a bit more precise, but those predictions are not getting any easier to live with. We *Homo sapiens* have been around for some 300,000 years, and in just a few generations we have made a huge change to the climate system of our planet, with the atmospheric carbon dioxide concentration higher now than at any time in the past several million years. We, and our elected politicians, need to begin treating the climate emergency as the emergency that it is.

PROFESSOR TREVOR MCDOUGALL AC recently received the 2022 Prime Minister's Prize for Science for his discovery of four new ocean mixing processes and his work to define the thermodynamic properties of seawater.



One person, one brain, two different types of MRI scans. The right side is not fairy floss – it shows the cables formed by bundles of individual brain-cell fibres, or axons.



Do we understand the brain yet?

The past decade saw billion-dollar projects tasked with decoding the brain. So, asks editor-at-large **Elizabeth Finkel**, how far did we get?

In August 2013, my first cover as editor of *Cosmos* magazine – an edition we themed "Decode your brain" – suggested we were on the verge of a new era of understanding how the brain works. As we approach the finish line on this "decade of the brain" – one in which multi-billion-dollar campaigns have sought to reveal the workings of the most complex thing in the universe – it seems a good time to ask: are we there yet?

It wasn't the first decade of the brain. Previous iterations had promised a similar neural booty, such as new treatments for schizophrenia or spurring the development of AI. But this campaign was on steroids. For one thing, it was a twin effort.

In early 2013, Europe launched its flagship "Human brain project", the goal of which was to simulate a human brain inside a computer within a decade. (Spoiler alert: it didn't happen. For more on how that project panned out, visit *www.human-brainproject.eu/en/*)

The US countered with President Obama's Brain Research Through Advancing Innovative Neurotechnologies (BRAIN) Initiative, tasked with more pragmatic aims, such as developing circuit diagrams of the brain.

Overall, neuroscientists were armed with techniques that even two decades earlier had been the stuff of sci-fi.

Think microscopes that peer into the brain of a living animal to record signals from individual brain cells or neurons. Add the ability to switch particular brain circuits on or off with pinpoint precision using a pulse of light, a technique called optogenetics. Mix in brain atlases with the dynamic resolution of Google maps, from full-relief technicolour maps of the wrinkled brain surface down to microscopic scale charts of the brain's cellular structure. (To take a fantastic voyage through the human brain, take a look here: *https://julich-brain-atlas.de/*)

Add circuit diagrams dubbed "connectomes" to satisfy the most exacting electrical engineer. Just as geneticists needed the genome – the complete genetic code – to understand the logic of life, so too the connectome would underpin the logic of brain function.

This amazing bag of tricks has enabled researchers to begin the task of linking the electrical signals in brain circuits to such elusive things as behaviour.

"The last decade has seen us move towards closing the explanatory gap," says Australian National University neuroscientist Professor John Bekkers, who has spent his career analysing brain circuitry.

So: do we finally understand the brain?

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Known knowns

It's a meme that the brain tends to be understood in terms of the most advanced technology of the day.

For imperial-era Romans, the brain was an aqueduct. The 17th-century natural philosopher René Descartes saw it as a hydraulic machine, like the ones that moved statues in Versailles. Among late 19th-century folk it was comparable to a telephone exchange. The 20th century finally nailed it: the brain is a computer. It takes in information, stores and processes it and delivers an output; moreover, it does so by sending electrical signals through its circuits.

Of course, it doesn't have the architecture of 20th-century computers. It's more akin to what the 21st has delivered – the neural networks that recognise faces in smartphones, and have now given us chatbots that pass the Turing test. It's no surprise that brain and bots share similarities in their architecture: these machines were modelled on our brain architecture in the first place.

Still, artificial neural networks are a crude facsimile of a human brain, whose 80 billion neurons and 100 trillion connections give rise to our perceptions, intelligence, emotions, and consciousness.

"It's the complexity of scale," notes Professor Gerry Rubin, director of the Howard Hughes Medical Institute's Janelia Research Campus in Virginia, where imaging techniques to spy on individual brain cells were developed and the fruit fly connectome project began.

Moreover, Rubin says the brain computer may not be logical. "It was built by evolution; not an engineer. The analogy I like is you went from the Ford Model T into a Maserati without ever being able to turn the engine off."

Brains are also famously more efficient at learning than artificial neural networks are – something that Dr Brett Kagan and his colleagues at Cortical Labs in Melbourne are exploring in "dish brain" – human brain cells that can learn to play *Pong*, a first generation computer game.

So yes: the brain is fantastically complex and different from the computer on your desk. But if the goal is to decode brain signals, we've made some fantastical strides – at least, if the last decade of headlines are anything to go by.

"The brain was built by evolution; not an engineer. The analogy I like is you went from the Ford Model T into a Maserati without ever being able to turn the engine off."

Can we see what our brains see?

In 2011, UC Berkeley neuroscientist Jack Gallant (top) set out to decode people's internal visual experiences. Participants watched several hours of Hollywood trailers while in an fMRI machine, and from this an algorithm was created that could associate brain activity with visual patterns for shape and motion. Participants then watched a fresh round of trailers while their brain patterns were recorded. The lower right image is the algorithm's attempt to decode the brain pattern of a participant watching a clip of Steve Martin as Inspector Clouseau (lower left).

Neuroscientist Professor Jack Gallant at the University of California (UC), Berkeley, can tell what movie a person is watching by decoding their brain waves on a functional magnetic resonance imaging (fMRI) machine.

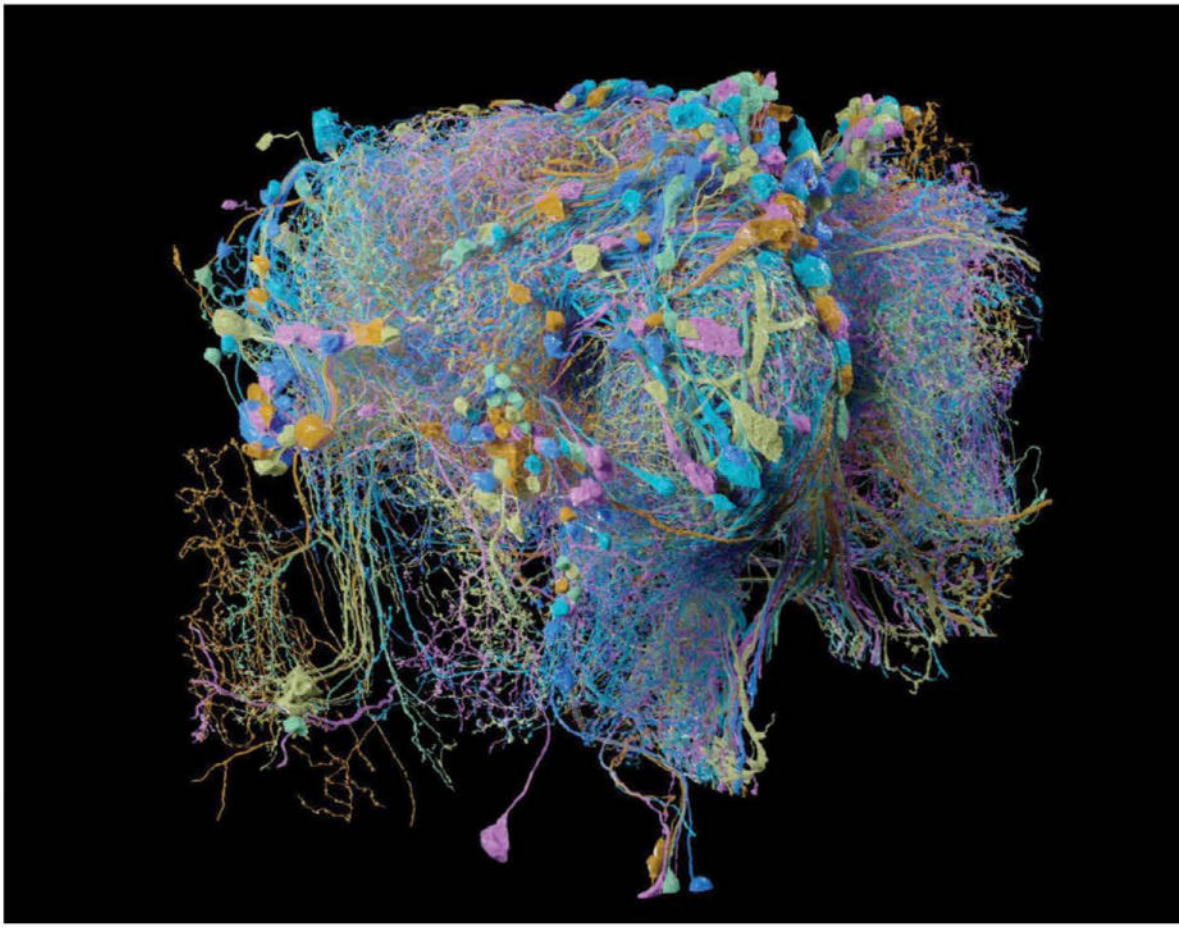
Dr Joseph Makin at UC San Francisco inserted electrodes into the brain of epileptic patients undergoing diagnostic tests and converted their thoughts to text. Professor Doris Tsao, also at UC Berkeley, can identify the face a monkey is looking at by reading signals directly from wires connected to 205 brain cells.

Then there are the mice who can be triggered to hunt and kill at the command of a laser light – by optogenetics. In another study, the romantic urges of voles were triggered using optogenetics to activate a different set of circuits.

These examples seem to proclaim loud and clear: we are learning how to crack brain codes. Yet according to neuroscientist Professor Karel

UC BERKELEY/YOUTUBE

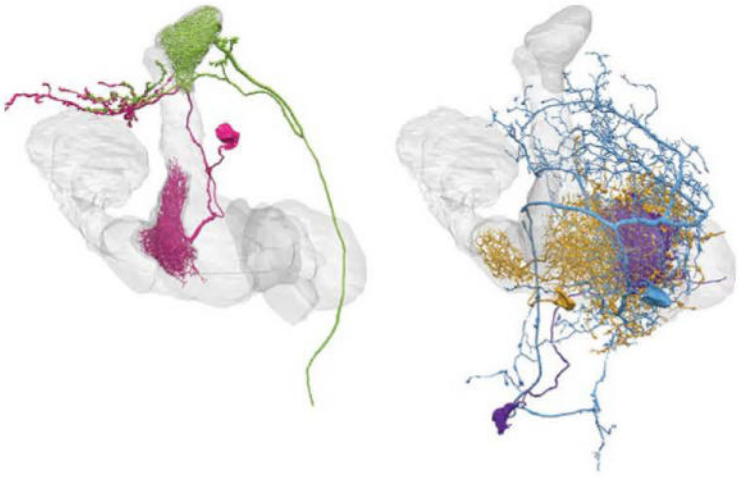
This image (right) zooms into a small region of the fruit fly connectome shown below. The fruit fly brain is dazzlingly complex; yet it only has 100,000 neurons compared to a human's 80 billion.



Gerry Rubin, director of the Howard Hughes Medical Institute's Janelia Research Campus, Virginia

TOP RIGHT: THE FLYEM TEAM, JANELIA RESEARCH CAMPUS, HHMI (CC BY 4.0). RIGHT: FLYEM/JANELIA RESEARCH CAMPUS.

Be a fly on the wall (of a fly's brain)



In 2020, researchers at the Janelia Research Campus in the US created the most detailed wiring diagram yet of the fruit fly brain, tracing the paths of 25,000 neurons and their 20 million points of connection. This image zooms in on the "mushroom body", a region involved in learning and memory. Researchers have been interested in it for over 20 years, but now having a big-picture diagram allows them to map how the brain is put together. For example, they've discovered that separate sets of neurons connect the mushroom body to the visual and olfactory regions, suggesting that flies can make memories using sight and smell individually.

Svoboda, at the Allen Institute in Seattle, these are "parlour tricks".

Tsao agrees: "What we know about the brain, including my own work, is trivial."

Known unknowns

No doubt, these brain scientists are reprising the age-old truism articulated by explorers since the time of Aristotle: the more you know, the more you know you don't know. Or as Tsao puts it, "whatever you already understand is trivial and boring".

Nevertheless, as neuroscientists peel back the curtain on old mysteries, new vistas open up – both down into the molecular details and up into the vast cloud of emergent properties.

For Svoboda, the direction of interest points deeper into the underlying circuitry. When he refers to mind-reading breakthroughs as "parlour tricks", he means they are relying on correlation. Researchers like Gallant and Makin record brain signals when a person is watching a movie or articulating words, then feed them into a machine-learning algorithm that learns to associate the patterns, in much the same way these algorithms learn to detect cats on your phone.

For Svoboda – who aims for nothing less than reverse engineering the circuitry of the brain – that's not very informative. He and his colleagues

are making headway in reverse engineering the mystery of short-term memory: the type that allows you to remember 10 digits long enough to tap them into your phone or follow instructions to turn right or left at the next street.

The mystery of long-term memory, that needed to permanently remember the phone number, was at least partially revealed in the 1960s. When neurons in the hippocampus (a sea-horse shaped structure involved in making memories) fired together in synchrony with neurons from other parts of the brain – say five times a second for several seconds – that soldered them together in a circuit. That soldering was dubbed "long-term potentiation". In 2014 Roberto Malinow, a neuroscientist at UC San Diego, artificially induced that soldering by rapidly flicking an optogenetic light switch on and off to create a fake memory. The experiment proved that long-term potentiation was the mechanism behind long-term memory.

Short-term memory has remained more elusive. One long-standing theory proposed by physicist Professor John Hopfield in the 1980s suggested it involved reverberating signals between a set of neurons – as if they were humming a tune.

Svoboda has now provided evidence that this actually takes place. A recent experiment in his lab conducted by Kayvon Daie found that a circuit of some 50 neurons in the anterior lateral motor cortex (a part of the brain known to make decisions about movement) held the memory of whether a mouse should lick left or right to get a drink of water.

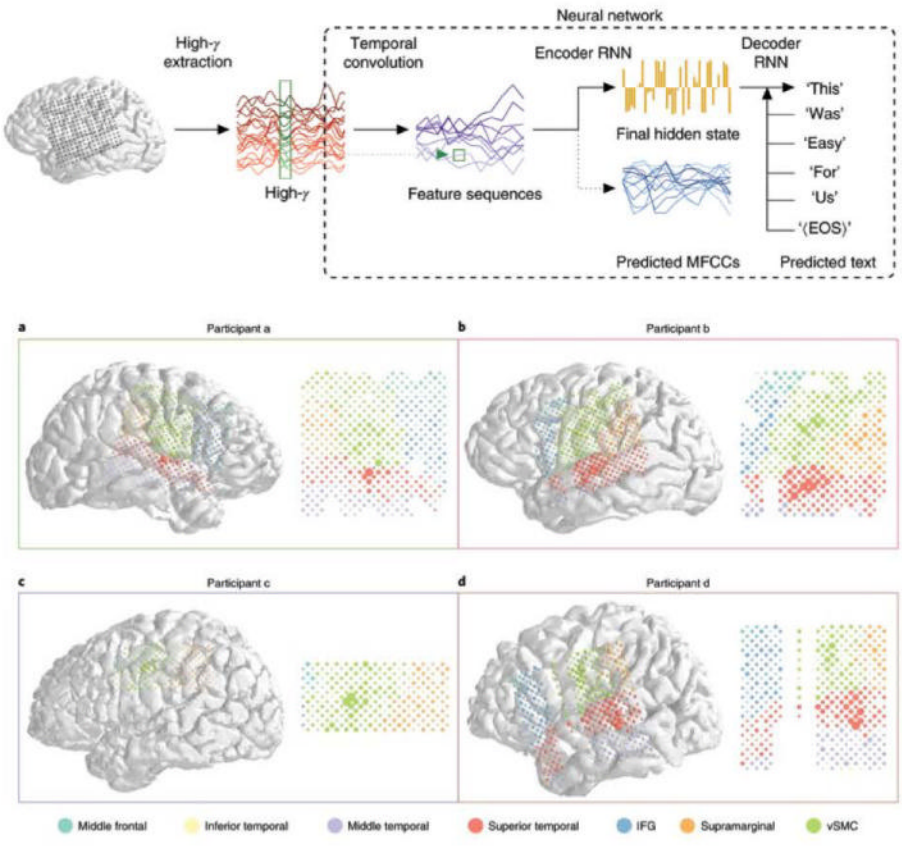
Daie pretrained the mice with a musical tone. A high pitch meant a drink of water lay to the right; a low pitch on the left. He observed what was happening in the mouse's brain via a tiny window in its skull that had a microscope attached to it, with a view of about 500 cells. Thanks to some nifty genetic engineering, every time a neuron fired a signal, it flashed a fluorescent light detected by the microscope. (Calcium is released when a neuron fires and the neurons were fitted with a calcium-sensitive

As neuroscientists peel back the curtain on old mysteries, new vistas open up – both down into the molecular details and up into the vast cloud of emergent properties.

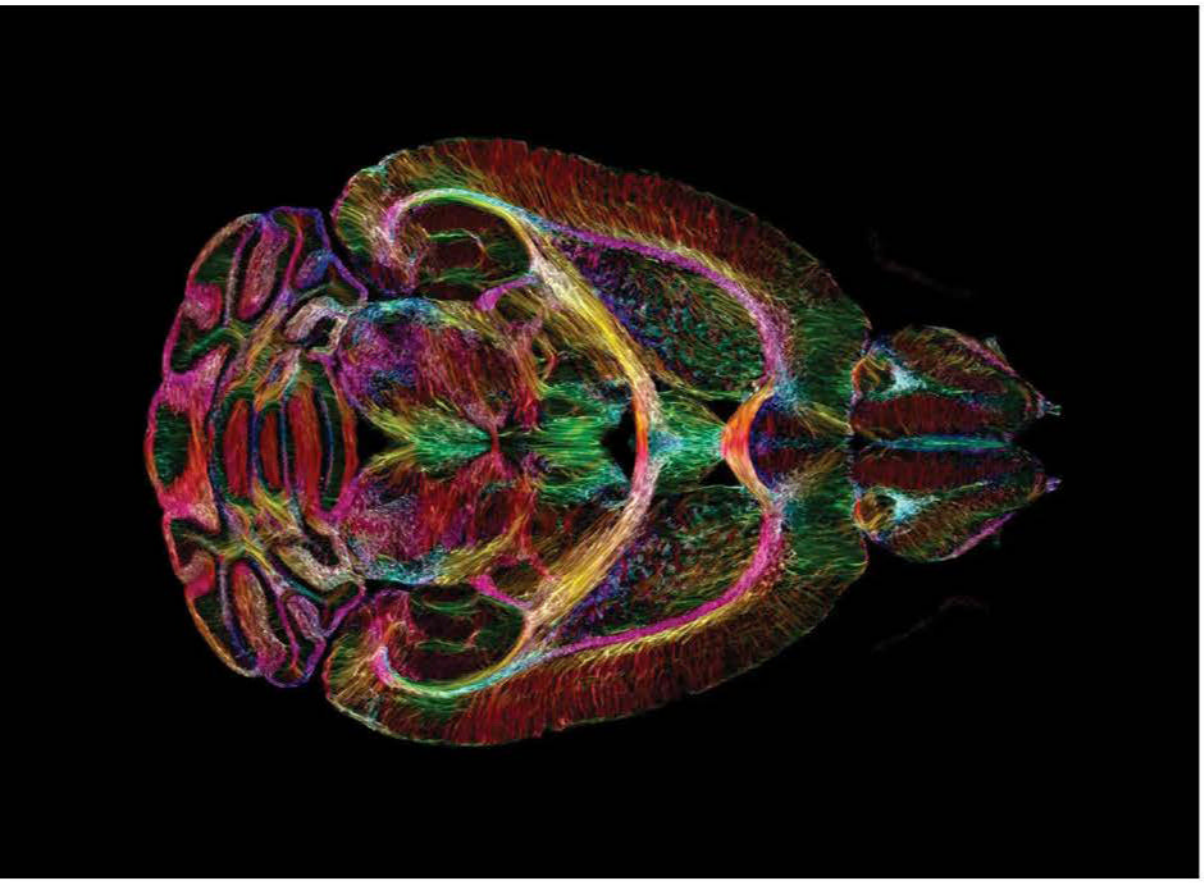
Dr Joseph Makin, UC San Francisco

Hey Google, read my brain

Makin's 2020 study achieved high accuracy and natural speech rates by applying a machine-translation algorithm – the kind used by Google – to electrocorticograms. These are recorded by placing electrodes on the exposed brain surface of people with epilepsy who are undergoing diagnostic tests (a,b,c,d, right). They trained an artificial neural network by feeding it brain signals recorded while participants spoke a series of 30–50 sentences, plus their transcriptions. When the participants spoke the sentences again, the signals were fed into a "decoding pipeline", where an encoder-decoder recurrent neural network (top right) predicted words in a sentence based on the previous word. The average word error was just 3%.



JOSEPH G.MAKIN, DAVID A.MOSES, EDWARD F.CHANG/SPRINGER



This high-definition diagram of a mouse's entire brain was created using a powerful combination of MRI and light-sheet microscopy.

Professor Karel Svoboda, Allen Institute, Seattle

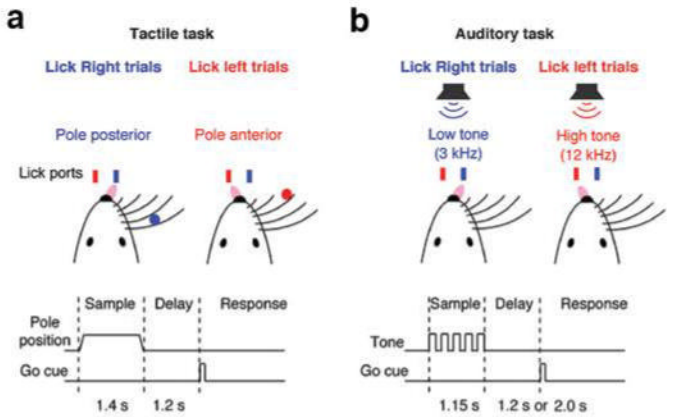
dye.) Just prior to each lick, some 50 neurons fired together for a few seconds with a particular frequency, like a recognisable hum. Could they be encoding the memory of licking right? To check, Daie artificially stimulated those same neurons with a light switch. The mice licked right.

Away from the mice, Daie retreats to his computer to test models that describe how these networks behave. One of the most promising is the "attractor model", which theorises that these circuits establish pre-existing templates to help complete a memory. This may be linked to our minds' strong tendency to complete patterns or see a face in a cloud.

Another stunning case of reverse engineering behaviour comes from fruit flies. Insects have legendary navigational abilities: bees unerringly find their way from the hive back to a food source and communicate its whereabouts to others via their waggle dance; foraging desert ants navigate across hundreds of metres of featureless landscape back to their nest.

Fruit flies aren't quite in the same league, but they have the basic navigational kit. Along with colleagues at Rockefeller University, Professor Larry Abbott – a physicist-turned-neuroscientist based at Columbia University – has decoded it. Fruit flies held in place by miniature harnesses

Humming neurons encode a memory of which way to lick



Kayvon Daie at the Allen Institute trained mice to associate a musical tone with the location of a water reward a few seconds later. For instance if the mouse hears a high tone, the water will be on the right. Just prior to each lick, Daie saw that 50 neurons in the motor cortex fired together at the same frequency for a few seconds like a recognisable hum. By triggering them with a light switch, Kayvon Daie showed the neurons were encoding the memory to lick right. Subsequently, a series of studies used both tactile cues and musical tones to train mice to lick a left or right pole. The researchers' goal is to simultaneously observe the mice's brain activity to see if they are encoding the short-term memory of which way to lick.

TOP: DUKE CENTER FOR IN VIVO MICROSCOPY; RIGHT: TSAI-WEN CHEN, NUO LI, KAYVON DAIE, KAREL SVOBODA/SCIENCE DIRECT.

roamed a virtual environment while a microscope attached to their heads recorded the activity of individual brain cells.

It turns out that to keep track of where they were, fruit flies carried out a mathematical calculation taught to high school students: vector addition. The ability to reverse engineer the circuitry of a navigating fly relied on having the entire wiring diagram, the connectome.

"In flies we can now test theories with the precision I was used to in physics," enthuses Abbott.

Fly brains are a very long way from ours, but that doesn't mean they won't hold compelling lessons for decoding the human brain: evolution tends to re-use good inventions. A dramatic example is the eyeless gene, first discovered because it was crucial for the development of the fruit fly eye. It was subsequently found to be crucial to human eye development too.

For Professor Stephen Smith at the Allen Institute, the compelling questions are even more fine-grained. Smith has spent much of his career focused on the synapse, the place where connections between neurons are strengthened or weakened. Like sprawling tentacles, a single neuron is equipped with thousands of incoming synapses, each relaying a hopeful message from another neuron. Whether or not a neuron will accept that invitation to join part of a brain circuit is determined by what happens at the synapse.

And that, believes Smith, is determined by the genes in play there. It turns out that neurons use more genes than any other type of cell. Hundreds of chemical messengers called neuropeptides are deployed at the synapse, different ones in each of

"It's a beautiful example of encoding, neuron by neuron. A few years back, I'd have said nobody's ever going to get there."

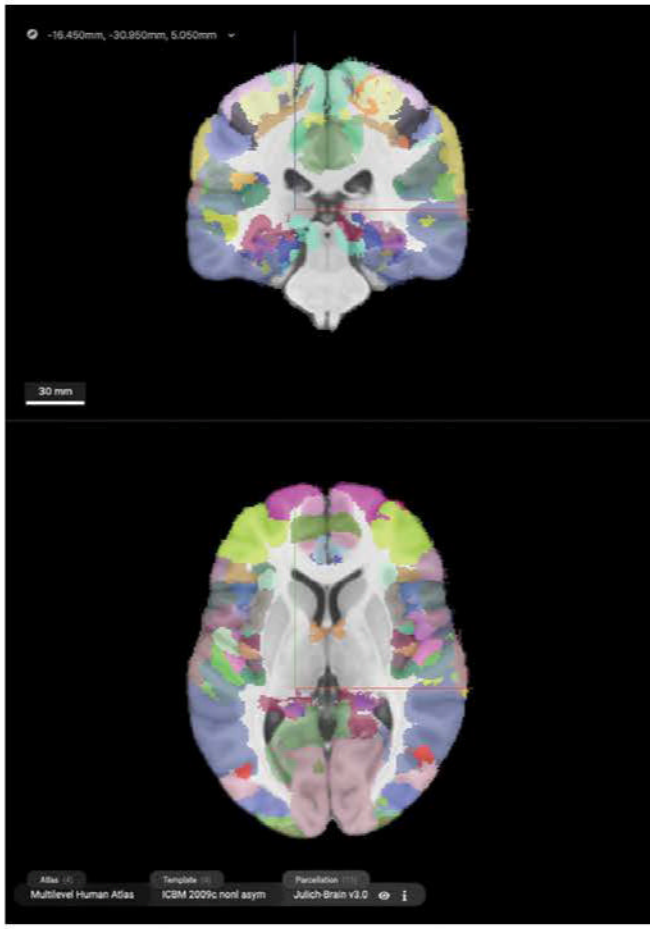
the 4000 or so neuronal cell types that Smith has analysed. He believes it's these neuropeptides that determine which neurons will link into circuits, like those that underlie short term memory.

Unknown unknowns

Other researchers are champing at the bit to leap to higher dimensions.

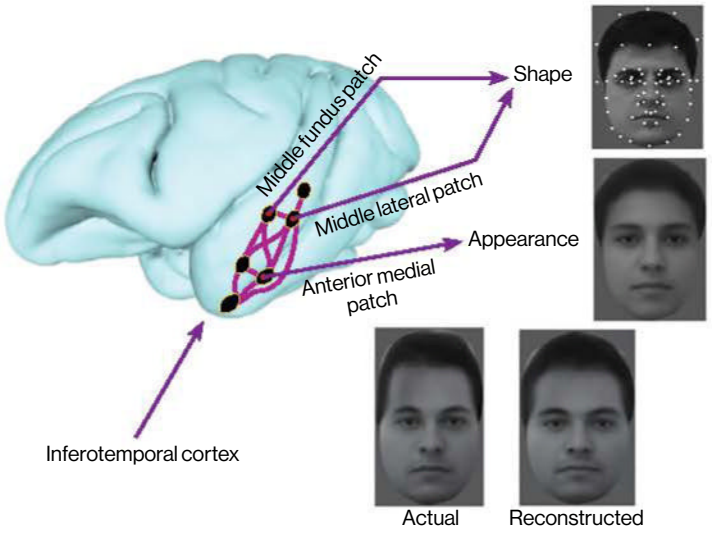
Tsao's work to date has reverse engineered how the monkey brain reads faces. She found it takes only 205 neurons in a region of the brain called the inferotemporal cortex to encode a face. The neurons

Google Map of the brain: The Julich-Brain is the first 3D brain atlas, allowing users to zoom in from the wrinkled surface to high-resolution maps of the brain's cellular architecture.



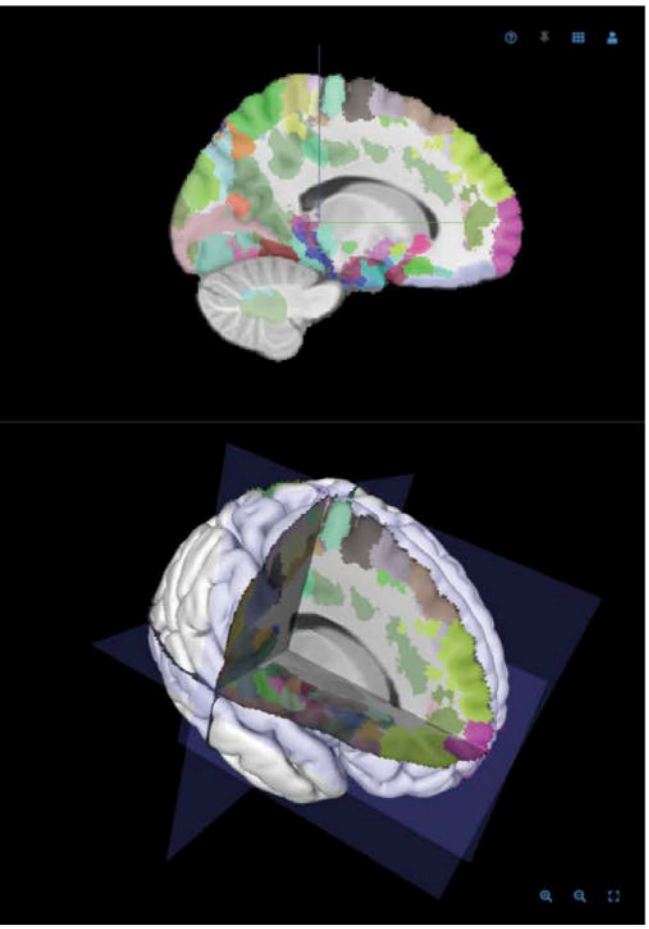
Professor Doris Tsao, UC Berkeley

Cracking the face code



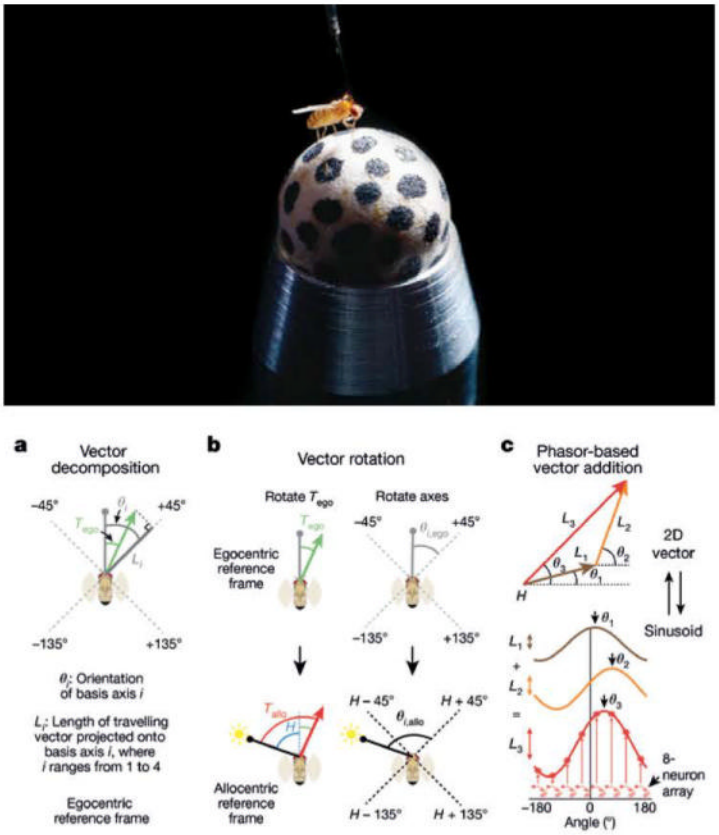
To reverse engineer how the brains read faces, Tsao's lab had to derive quantitative measures. They came up with 25 features for shape (i.e., features that define the skull, like the width of the head or the distance between the eyes) and 25 for appearance (i.e., features that define the face's surface texture, like complexion). Tsao found it takes just 205 neurons to measure these features and then put them together like a detective's identikit.

LEFT: LE CHANG, DORIS Y TSAO, NATIONAL LIBRARY OF MEDICINE & SCALABLEBRAINATLAS.INCFORG



ABOVE: ATLASES.EBRAINS.EU. TOP RIGHT: ROCKEFELLER UNIVERSITY.

Not your typical session at the gym



A fruit-fly treadmill (top) is the norm for researchers at The Rockefeller University's Integrative Brain Function lab. By observing flies navigate on the treadmill while recording brain activity, the team found that the flies' neural circuitry updates their internal compass at they turn. This means they navigate from external landmarks (allocentric reference frame, as seen in (b)) rather than in relation to their own body (egocentric reference frame, (a)) . Flies can also perform vector arithmetic, rotating, scaling, and adding vectors to compute travelling direction (c).

are arranged in six face patches. Cells in each patch are tuned to a different facial feature. Some act like rulers to measure the distance between the eyes; others detect the face's orientation – is it looking left or right? Yet others are tuned to the colour of the eyes or hair. In a process reminiscent of the way a detective assembles an identikit, it is the combined information delivered by these face patch cells that lead the monkey, or Tsao, to identify a specific face, regardless of its orientation.

The coding logic seems to generalise to other functions of the IT cortex, such as identifying whether an object is animate (like a cat) or inanimate (like a box).

"It's a beautiful example of encoding, neuron by neuron," says Abbott. "A few years back, I'd have said nobody's ever going to get there."

Tsao feels less triumphant. "I don't think any principle we understand is interesting yet," she says. "Everything we understand really well is still 'feed forward', wiring more and more complex feature detectors. I think there has to be something more to the brain than that."

A feed forward pathway transmits information forward without incorporating feedback en route, like kicking a football towards the goal. By contrast, the goalkeeper who assesses the cross-wind and ball spin is employing negative feedback.

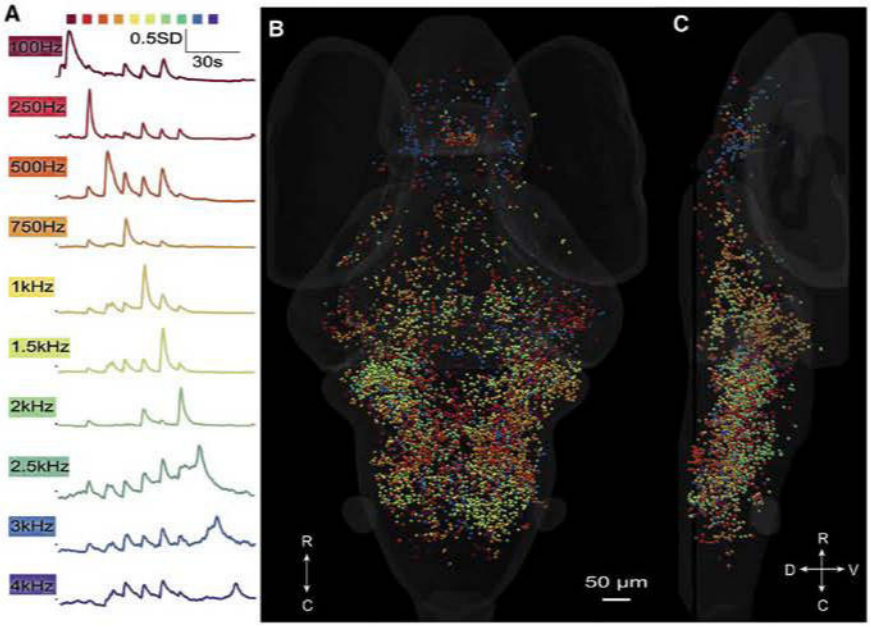
Professor Larry Abbott – a physicist-turned-neuroscientist based at Columbia University

For Tsao the next goal is to figure out how the brain incorporates various forms of feedback and puts it all together – what she refers to as the "outer loop" of the brain computer. How, for instance, does the brain bind perceptions together in three-dimensional space to give us a model of the world? Tsao suspects that the posterior parietal cortex (a region lying roughly at the top of the primate brain towards the back) will hold clues.

Professor Ethan Scott at the University of Melbourne may beat her to it – in a juvenile zebrafish. Scott can watch this transparent fish's entire brain thinking – a symphony of 100,000 flashing neurons. He can also record the particular sections

Baby fish DJ drops some beats

What happens when you combine an underwater speaker, zebrafish larvae and whole-brain imaging? It's more than just a fish disco – you also get data on how fish process audio. University of Queensland researchers played the larvae different frequencies, as well as white noise and sounds mimicking running water or other fish swimming past, and recoded how their neural circuits lit up in response. They have also recorded brain-wide activity of zebrafish (below) while presenting images and motion stimuli, in an effort to understand how the fish make sense of their world.



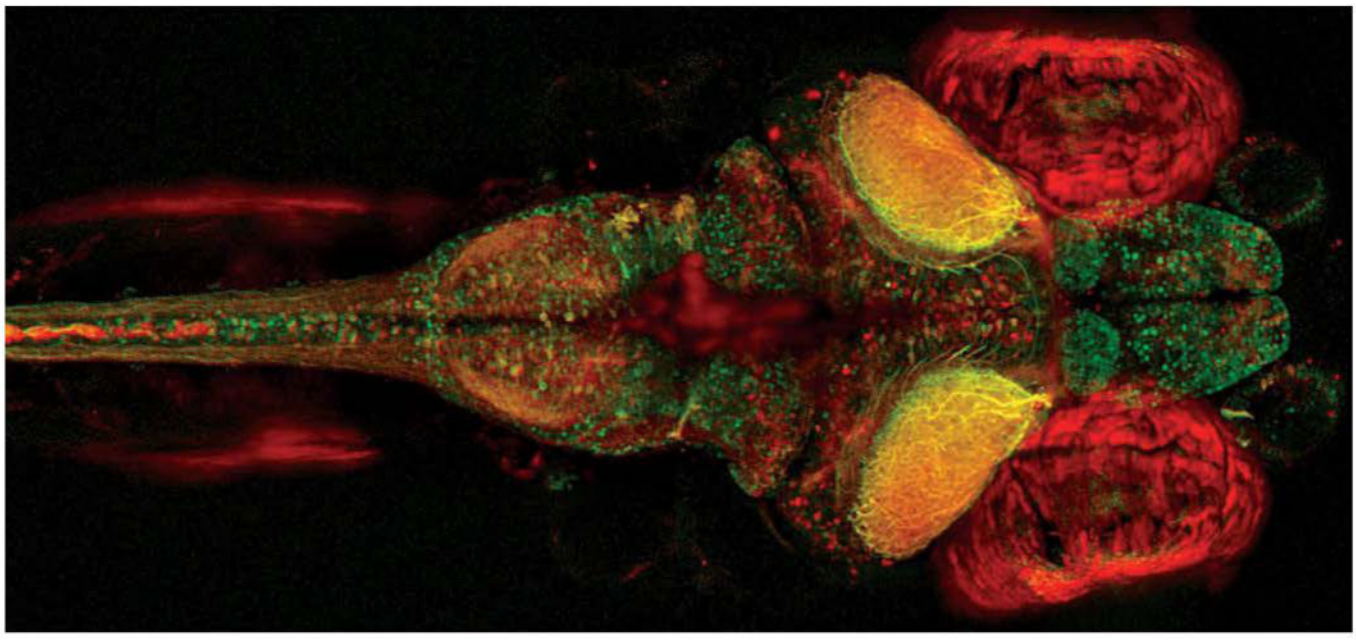
that perform when the fish listens to threatening sounds, while also sensing the flow of water and maintaining its balance. These signals all appear to be bound together in an area of its brain called the tectum – the equivalent of a mammal's superior colliculus.

Like many 21st century neuroscientists, Scott has his work cut out trying to decode the activity of thousands of neurons firing at once. "The problem used to be collecting data like these," he says. "Now we are flooded with data." Progress, he says, will rely on "collaborations with theoreticians and mathematicians".

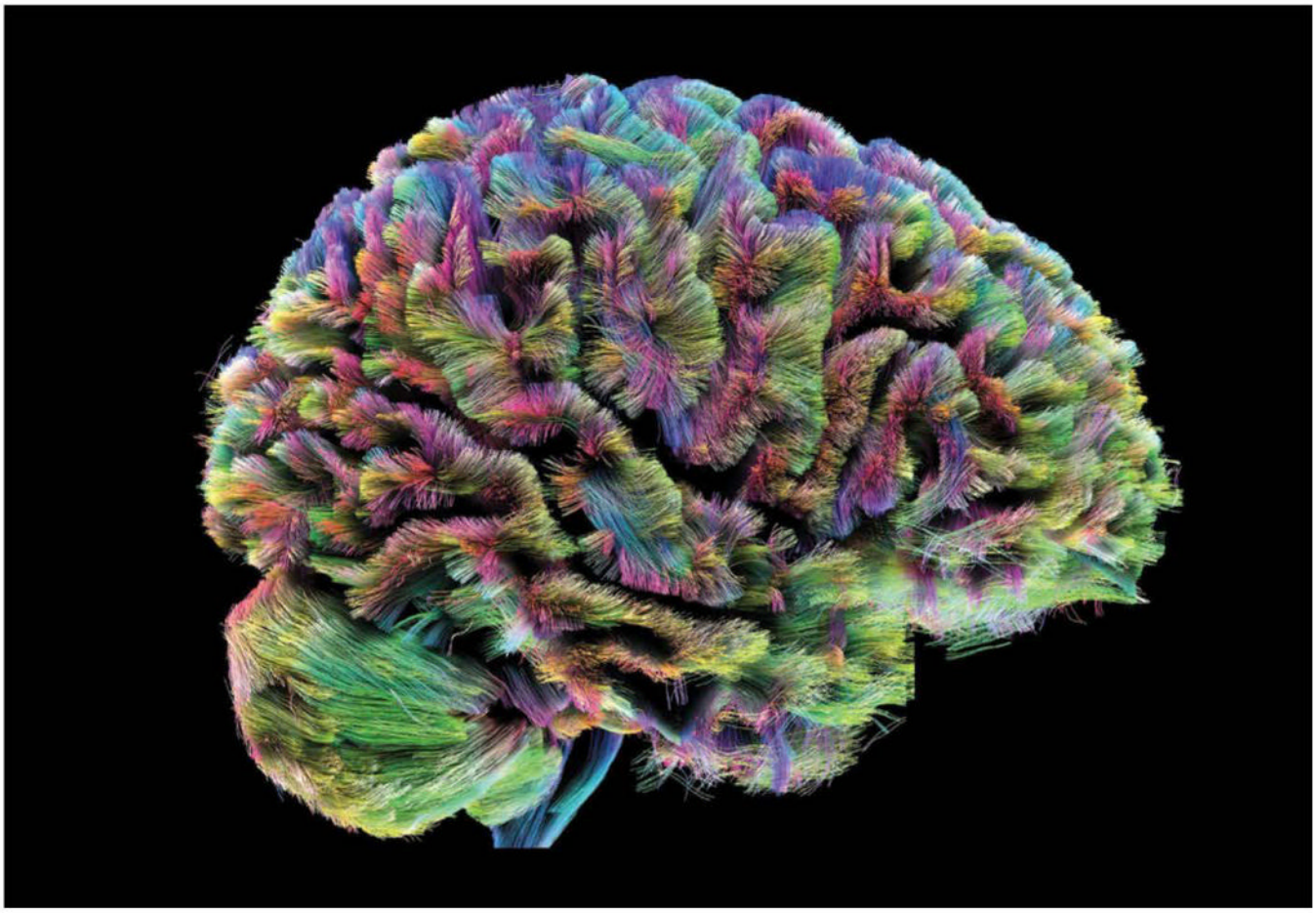
Professor Ethan Scott of the University of Melbourne

Perhaps some of the outer loop properties – like consciousness – will always defy any attempt at reverse engineering. Once a system gets to a certain level of complexity, it may be beyond the scope of reverse engineering. In a famous 2017 example, neuroscientists Eric Jonas and Konrad Kording tested whether their approach to reverse engineering brain circuits would allow them to explain the workings of a much simpler system – the 6502 gaming chip for playing *Donkey Kong*. They couldn't.

And no-one has any idea how deep learning machine algorithms eventually arrive at their answers. For Abbott that's not surprising. Coming



TOP: VOL 31, ISSUE 9, ELSEVIER. LEFT: UNIVERSITY OF QLD.



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The fairy-floss brain is what you see when you use fMRI to zoom in on the diffusion of water molecules that follow tracks created by axon cables – thousands of axons neatly bundled together as if by an electrical technician to connect up different parts of the brain. The technique is known as diffusion tractography. Combining this data with modelling algorithms is the next step – read what's coming next in Richard A. Lovett's story on page 78.

"I think we could understand what every neuron in the brain is doing and we still won't have an understanding of something like consciousness."

from physics, he's comfortable with the idea that the ability to describe matter changes with scale. A hydrogen atom is completely describable by quantum mechanics, but that description can't be used for a plank of wood.

"In neuroscience I think we could understand what absolutely every neuron in the brain is doing and we still won't have an understanding of something like consciousness," he says.

For Tsao, "The path to understanding consciousness is going to come from AI. I think until we can experiment with it like the way we can with vision, we won't understand it." And with the current performance of AIs, she thinks the day they develop consciousness is close.

So do we understand the brain yet?

Despite the breakthroughs of the last decade, most neuroscientists say we're just at the very beginning. It's as if we've discovered an alien computer. We've unpicked some of its hardware and are just learning to decode some of its simpler routines, but the mysterious outer loops loom before us, like a vast impenetrable cloud.

Whether we can ever penetrate that fog remains an open question. The researchers interviewed here, equipped with ever-more fantastical instruments, are accelerating their efforts to push ahead at all scales: drilling down to the microcircuitry of single synapses like Stephen Smith; decoding discrete circuits like Karel Svoboda and Larry Abbott; computing the thinking brain of zebrafish like Ethan Scott; and seeking to explain how the primate brain binds perceptions, like Doris Tsao.

Each would offer a different timeline for finally "understanding the brain". But there's one thing they all agree on. The next decade – with its ever-accelerating dialogue between artificial and natural intelligences – will be the one to watch.

ELIZABETH FINKEL is *Cosmos*'s editor-at-large. Her last story, about Denisovan DNA, appeared in Issue 91 and was included in *Best Australian Science Writing* 2022.

The team behind a novel approach to fighting dengue fever – which was first tested in Australia and demonstrated at scale in Indonesia – is gearing up to launch its most ambitious phase yet. **Clare Watson** reports.

BACTERIA VS VIRUS: death of dengue?

In an unassuming red-brick building on the southside of Colombia's second-largest city, Medellín, millions of mosquitoes are bred each week to combat dengue fever. One's natural instinct is to recoil at the metallic smell of blood wafting out of a humid room where netted cages hold thousands of mosquitoes. But these blood-sucking insects are part of a daring strategy to rid cities like Medellín of dengue fever, one suburb at a time.

From the backs of motorbikes and out car windows, adult mosquitoes are spread across the city and neighbouring urban areas of the Aburrá Valley that is home to three million people. These *Aedes aegypti* mosquitoes have been bred to carry *Wolbachia*, a species of bacteria naturally found in up to 60% of insect species, but not usually *A. aegypti*. When it is, *Wolbachia* stops *A. aegypti* from transmitting viruses to humans.

Only a few years ago, dengue fever was rampant in Medellín. But since the non-profit World Mosquito Program (WMP) started releasing its modified mosquitoes in 2017, dengue case numbers have plummeted to their lowest levels in 20 years. It's the largest continuous release of *Wolbachia*-infected mosquitoes anywhere in the world, and dengue incidence is down by 94%.

According to Cameron Simmons, an infectious disease scientist at Monash University and WMP's director of global implementation, the challenge now is "to industrialise the supply of *Wolbachia*" to reach more cities. Now, the program's planned expansion is moving into its most ambitious phase yet.

Backyard beginnings

It's a technique that was first trialled in Townsville almost a decade ago. An affable entomologist by the name of Scott O'Neill had been researching how the *Wolbachia* bacterium, taken from flies, shut off *A. aegypti*'s ability to transmit dengue and

(ALL MOSQUITOES) PIMAN KHRUTMUANG/ADOBE STOCK. RIGHT: APU GOMES/GETTY IMAGES

Prototype dengue destroyers: *Aedes aegypti* mosquito larvae infected with *Wolbachia* bacteria are sorted by a researcher at the Fiocruz Institute in Rio de Janeiro, Brazil. The mosquitoes, which can't spread dengue, zika and chikungunya fever, were released from August 2017.

other viruses. Scientists still aren't exactly sure of the mechanism, but they think *Wolbachia* piques the mosquito's immune system, which stops the virus replicating, and also outcompetes the virus for critical resources.

Being a bacterium, it spreads through mosquito populations of its own accord. Another early experiment to simulate a real-world release with caged mosquitoes, by O'Neill and his team at The University of Queensland, indicated how with a few weekly top-ups of freshly infected mosquitoes, *Wolbachia* could sweep through contained populations within a few generations.

But then came the same stumbling block faced by other mosquito-control methods: how to roll out the technology citywide. To overcome this, O'Neill had to trial releasing modified mosquitoes in a community willing to give it a go. Townsville in northern Queensland might seem an unlikely choice, with the disastrous consequences of introducing cane toads still fresh in people's minds. But the town was game; as scientists explained, *Wolbachia* is a Trojan horse of sorts, with little effect on *A. aegypti* mosquitoes other than curtailing their short lives and quashing their ability to spread viruses.

Over 28 months, starting in late 2014, some four million mosquitoes were released from plastic tubs and takeaway food containers in backyards across Townsville. Residents became "Wolbachia Warriors" and primary school kids joined in too. Sampling showed *Wolbachia* quickly spread to local *A. aegypti* populations as the lab-bred mosquitoes mated with wild ones.

This is the main advantage of using *Wolbachia*: unlike repeatedly spraying insecticides to control mosquitoes, the bacterium and the mosquitoes it infects do much of the hard work. The bacterium is passed from a female mosquito to her offspring

> "I just thought this was another enthusiastic scientist, with a solution for dengue that was going to crash on the rocks of disappointment."

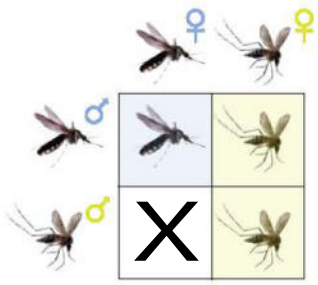
so none of them become viral vectors, and if an infected male mates with a female mosquito without *Wolbachia*, her eggs won't hatch. Once more than about 30% of mosquitoes in an area are infected , *Wolbachia* spreads through the population in a self-sustaining way, no more releases required (though close monitoring continues).

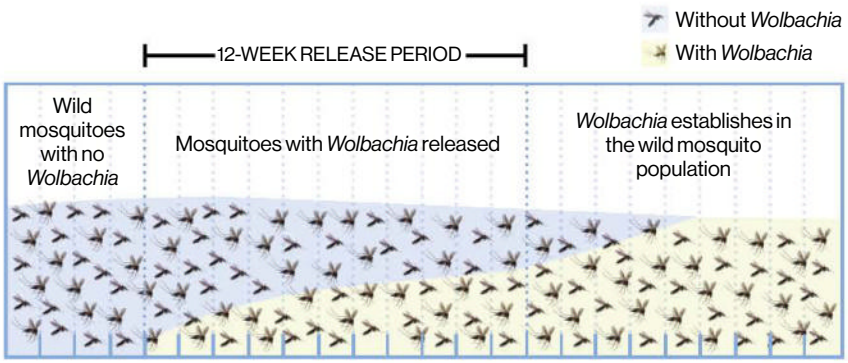
Within months of releasing the first batches of mosquitoes in Townsville, suburbs had upwards of 80% of mosquitoes carrying *Wolbachia*. Once the whole city was covered, 66 sq. km in total, locally acquired dengue fever was effectively stamped out and imported cases were trending in the same direction. However, the study had no control areas without mosquito releases with which to compare. Still, O'Neill, now at Monash University in Melbourne, and his colleagues were optimistic they could gather more data in time from places with a far greater dengue disease burden than Australia – data that they hoped would convince others their approach really worked.

Netting new evidence

Fast forward 10 years and the World Mosquito Program (WMP) has now deployed its technology in select cities in a dozen countries. In each one, initial hesitation about whether or not the approach would work in local communities has been overcome with

MOSQUITO MAGIC EXPLAINED





Wolbachia-infected mosquitoes are released over several months to spread through the wild population. When infected males mate with uninfected females, a mechanism called cytoplasmic incompatibility renders their offspring infertile. Meanwhile, *Wolbachia*-infected females remain fertile no matter who they mate with; their offspring carry *Wolbachia* and pass it on, spreading it without the need for further releases.

GREG BARTON

KEVIN FRAYER/GETTY IMAGES

successful pilot projects. "Success is long journey," says Simmons – and, he adds, it often hinges on feasibility.

The next leap is to establish a mass-breeding facility in Brazil, expected to be operational in 2024. WMP has already released mosquitoes in five Brazilian cities, but the new facility will be capable of producing up to 100 million mosquito eggs per week – enough to cloak many more of the country's sprawling urban areas in *Wolbachia*'s protection. Up to 70 million people in Brazil could be protected from dengue in the next 10 years, the program estimates.

Dengue fever remains the world's fastest-spreading mosquito-borne disease, and its grip on Brazil is growing particularly fast. Climate change coupled with rapid urbanisation is bringing millions more people into contact with *A. aegypti*. Cities across Asia have also recorded huge surges in dengue cases this past year. Singapore, for example, had its second-worst year on record in 2022, according to its National Environment Agency; more than 32,000 dengue cases were recorded, representing a six-fold jump on 2021.

Simmons has seen first-hand the havoc dengue fever wreaks on hospital systems when working on ward rounds in the early 2000s in Ho Chi Minh City, Vietnam. "When there are raging dengue outbreaks, hospitals suffer and patients line the hallways," he recalls. He also witnessed trial after trial end in disappointment; none of the drugs or antivirals ever tested for dengue fever delivered any real benefit.

To produce 30 million *Wolbachia*-infected mosquitoes per week, you first need to raise their young, and the world's largest mosquito "factory" (above) is the mass-production facility at the Sun Yat-Sen University-Michigan University Joint Center of Vector Control for Tropical Disease, in Guangzhou, China. Not surprisingly, a few mozzies always get away; lab technicians use electric racquets to kill strays.

So, when Simmons met WMP founder Scott O'Neill in 2010, whose idea it was to breed *A. aegypti* with *Wolbachia*, Simmons wasn't optimistic. "I just thought this was another enthusiastic scientist, this time from academia, with a solution for dengue that – like most other things – was going to crash on the rocks of disappointment," he says.

Simmons has since changed his tune, as have other epidemiologists, upon seeing the staggering reductions in dengue case numbers in areas where *Wolbachia*-infected mosquitoes have been released. After Townsville, studies in Indonesia, Vietnam, Colombia and Brazil have reported falling dengue cases numbers wherever *Wolbachia* mosquitoes have flown.

Most notably, a randomised, controlled trial – representing the gold-standard of clinical evidence – was conducted in Yogyakarta, Indonesia. Conceiving the trial was easy, says Simmons, but

designing it took several years and three more to run. A large chunk of the city was divvied up into areas with and without *Wolbachia*, so the team could directly compare dengue rates. The results, published in the *New England Journal of Medicine* in 2021, showed that releasing *Wolbachia*-infected mosquitoes reduced dengue incidence by 77% over 27 months compared to untreated neighbourhoods. Dengue-related hospitalisations also dropped by 86%.

The government of Yogyakarta province has since elected to roll out *Wolbachia*-carrying mosquitoes across the whole city and many of the urban areas surrounding it, Simmons says. "There's now nearly two million people in Yogyakarta province living with the benefit of *Wolbachia* in their local mosquito population."

That's just the beginning of WMP's plans in the Asia-Pacific region. The program is expanding into Bali, planning to release its first batch of modified mosquitoes on the island later this year, says Simmons. Pilot projects are also underway in Laos and Sri Lanka, while New Caledonia has decided to expand its pilot after early successes. But Brazil poses the biggest test yet, the first time WMP is attempting to disperse *Wolbachia*-infected mosquitoes nationwide.

While every country and city is different, Simmons says there are commonalities in how these societies work at the neighbourhood level. The program enlists the help of local health agents who do everything from vaccination to maternity care. Their involvement is "hugely important", Simmons says, in helping reach affected communities, especially those wracked by conflict. Drones are also being tested to disperse adult mosquitoes. Pellets of dried eggs to be plopped in water are likewise sent out in at-home kits.

> "We won't go into a community unless they show support for what we do. We don't wish to push the technology onto people."

But it can take months of consultation to ensure communities are on board with releasing *Wolbachia* mosquitoes in their local area. Part of the challenge is explaining to people who have been warned for decades of the grave danger

mosquitoes pose that these insects are now their ally in the fight against dengue fever. Building trust is also paramount.

"Community engagement is a very central element of what we do," O'Neill says. "We won't go into a community unless the community shows support for what we do. We don't wish to push the technology onto people."

However, dengue-riddled communities also know how little progress has been made by spraying insecticides. "Communities are quick to accept any intervention that can diminish this problem," says Maria Patricia Arbelaez, an epidemiologist at Colombia's University of Antioquia tracking the program's progress in Medellín.

Tomorrow the world

Not every city has seen such a steep drop in dengue case numbers, though. According to the WMP, studies in Rio de Janeiro, Brazil and Vinh Luong, Vietnam, have recorded smaller though still substantial reductions in dengue incidence, of 44% and 48%, respectively. The difference, Simmons says, is patchy coverage in Brazilian favelas where security concerns disrupt the best-laid plans, or only a small umbrella of protection in a bustling Vietnamese city where people come and go.

Dengue outbreaks also differ from place to place: every rainy season in Asia brings a spike in dengue cases, whereas the disease moves through

FROM LEFT: CHAIDEER MAHYUDDIN/GETTY IMAGES. WORLD MOSQUITO PROGRAM.

Latin America in waves that can be half a decade apart. This can muddy epidemiological findings that become clearer over time. "You need to be very patient," says Simmons.

Another randomised, controlled trial led by a different US team is already underway in Belo Horizonte, Brazil. And in a matter of months, WMP is expecting to hear the outcome of more than two years of consultation with the World Health Organisation, which has been considering, based on available evidence, whether to endorse the method as a dengue control tool.

WMP founder O'Neill says the results from Medellín and Yogyakarta demonstrate that the method can work at scale, in big cities, and protect millions of people from dengue fever. Projections also estimate that the healthcare savings from keeping people out of hospital would offset the cost of deploying *Wolbachia* mosquitoes within five to 10 years. "It's very rare to have a cost-saving intervention," says O'Neill.

"Then there's the real-world evidence," says Simmons. "When you look at the city of Yogyakarta, their dengue case numbers are lower than they have been for 30 years and north Queensland is essentially dengue-free. So if you ask people in public health in Yogyakarta or north Queensland 'does *Wolbachia* work?', the answer is very clear."

Gathering data about the technology's effectiveness against other diseases transmitted by *A. aegypti* might prove trickier – though that is the hope. Dengue is more predictable than Zika virus, yellow fever and chikungunya, which crop up sporadically. Trials need luck on their side to coincide with a disease outbreak or else it might seem like the technology does little to reduce disease burden. Encouragingly, a 2021 study found that chikungunya cases were halved in Niterói, Brazil, three years after releasing *Wolbachia* mosquitoes that also slashed dengue cases by 69%; however, Zika incidence only dropped by a third.

Another potential spanner in the works is that viruses might one day become resistant to *Wolbachia*, evolving an escape route to bypass the bacterium, as it does insecticides. Simmons says this is unlikely because of the many ways *Wolbachia* outcompetes a virus like dengue: hoovering up critical resources such as cholesterol, blocking its entry into cells and suppressing it by boosting the mosquito's immune system .

"We're not so naïve to think the virus will never escape," says Simmons. WMP's teams are monitoring for viral resistance to *Wolbachia* in mosquitoes scooped up from around Townsville, a decade after the technology was first deployed, and elsewhere. "But we hypothesise that it's going to take a very, very long time before that happens, so our expectation is that we're going to buy decades of protection."

Old-school efforts to control dengue's carriers can be far from healthy for those engaged in the work. In Banda Aceh, Indonesia (opposite, above), a worker uses a fogging machine to dispense insecticide. While the *Wolbachia*-infected mosquito breeding phase is high-tech, the local release program is anything but. Eggs bred in labs are shipped to their release area, where adult insects are reared in cardboard containers variously known as "mozzie boxes" or Zancu KITs (above). Project staff and local volunteers add water and the supplied egg and food capsules to the containers, from which adult mozzies emerge 1–2 weeks later.

CLARE WATSON is based in Wollongong, NSW. Her last story, on Chile's referendum, appeared in Issue 96.

Deep in the Top End's stone country, David Hancock joins Indigenous custodians restoring a revered spirit ancestor.

The Renewal of Naworo

Even people with long experience of rock-art sites would struggle to remain emotionless at Kudjekbinj (goo-jik-bin), a rock shelter about 320 kilometres east of Darwin, in the heart of Arnhem Land.

It's a majestic place in the shadow of an imposing escarpment. A massive slab of sandstone, some 25 metres long, lies separated cleanly from the rock above, its shiny surface rubbed smooth by generations of Bininj people – traditional custodians of this country. The presence of the ancestral figure of Naworo (nar-war-o) is palpable. This is his place, the surrounding land shaped by his journeys. According to Bininj senior custodian Terry Maralngurra, Naworo's body lies beneath the block of sandstone.

And there, above, only an arm's length away, is his imposing spirit. Few places in northern Australia hold such a close association between the physical and spiritual.

Conrad Maralngurra, his older brother Terry and other Traditional Owners of the Ngalngbali (nglun-bali) clan estate in Western Arnhem Land feared the revered painting of Naworo at Kudjekbinj was on the verge of disappearing. The white clay, or delek, that characterised the 9.5-metre painting had faded due to time and weathering.

After consulting with the clan, Conrad and Terry Maralngurra decided to revive Naworo, one of several nayuhyungki (na-yu-yungi) – ancestors – a giant, who arrived from the north to travel Arnhem Land thousands of years ago. They would repaint the image of the one-armed being with six fingers and six toes on the ceiling at Kudjekbinj.

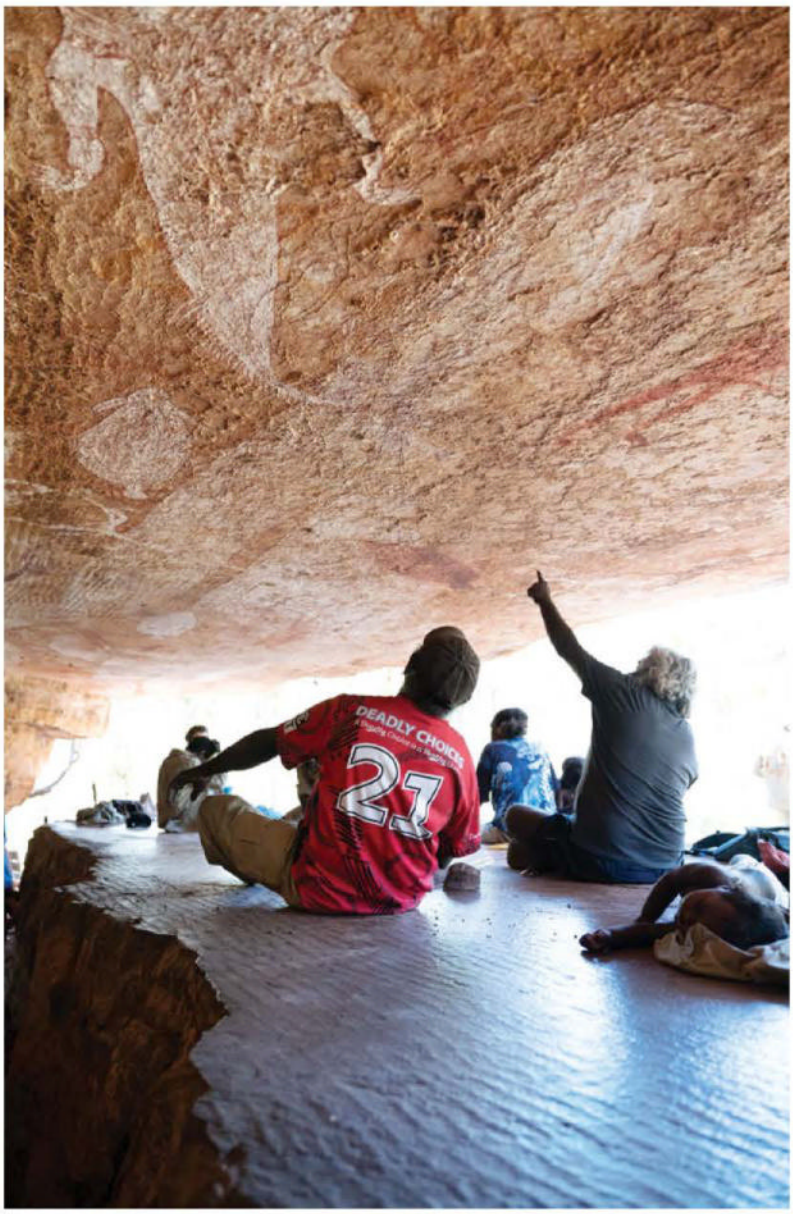
"When we were children, Naworo was alright," Terry says. "We didn't ever repaint because he used to renew himself. But today in 2023 we have to go and renew him and that is what we are doing now because there is no one there in that country.

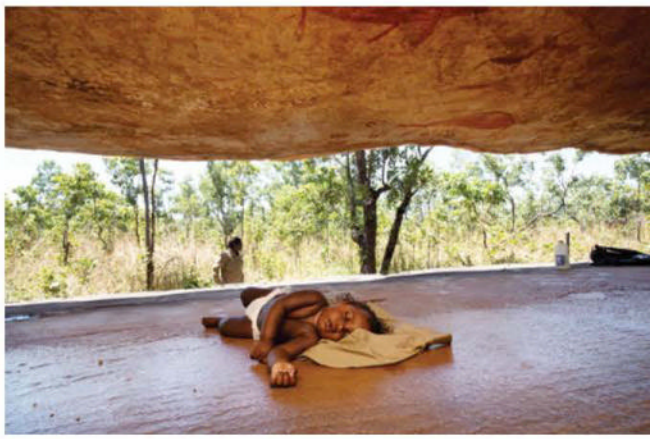
"That's what happens when you leave your country. The country is all alone and the story will fade away. Today he is lonely and slowly fading away. In the future when he knows people are back he will start to renew himself again."

Rock art is an integral part of maintaining culture in Western and Central Arnhem Land for Bininj people. Their traditional lands include the rugged 22,000-square-kilometre plateau known by speakers of Bininj Kunwok (dialects of the region) as Kuwarddewardde (gwart-ay-wart-ay) and by others as the "stone country". Kuwarddewardde borders Kakadu and Nitmiluk national parks in the west and south-west, and takes in the Warddeken Indigenous Protected Area (IPA) and parts of the Djelk IPA and Mimal land management area.

The plateau's Kombolgie sandstone, which formed about a billion years ago, has been carved by wet and dry seasons over eons, creating a network of fissures, chasms and gorges. The plateau's geological stability over this time has afforded

The faded image of Naworo (opposite) is surrounded by other paintings that represent plants and animals of the Western Arnhem Land region. Of particular interest are images of crocodiles, fish and marine creatures associated with Naworo's origins in the Arafura Sea, some 80km away.





plant and animal species protection from fire and flood and allowed them to evolve in relative isolation; some are found nowhere else on Earth.

Bininj, too, found sanctuary in the stone country for thousands of years but many were enticed away, forced out or died from introduced diseases when the region was explored and settled by balanda (Europeans) in the mid to late 1800s.

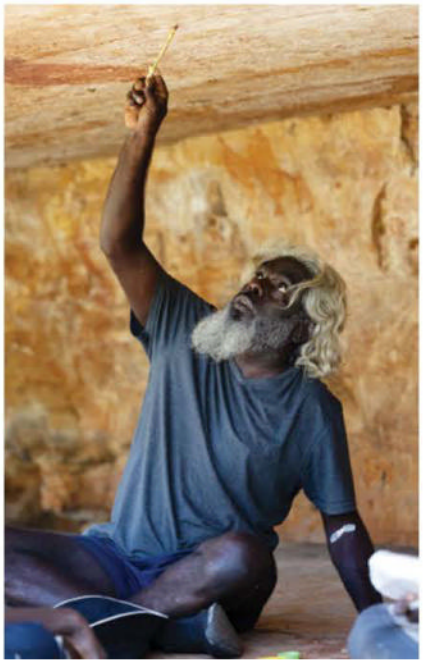
In the 1970s, some elders returned to Western Arnhem Land to establish small outstations, determined to revive traditional cultural and land management practices. The movement gathered momentum at the turn of the 21st century and was eventually recognised by the Australian government through the declaration of a number of Indigenous Protected Areas (IPAs). Some of these generated income for Bininj through managed burning and the sale of carbon credits.

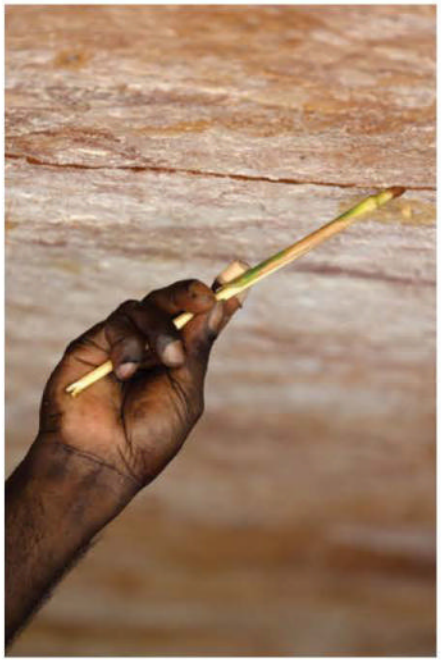
The long absence of a large population of Bininj meant vegetation built up and the region was at the mercy of wildfires that not only devastated wildlife but threatened rock-art sites and their priceless contents.

There are more than 125,000 known rock-art sites in Australia. Some contain grand galleries while others hold a single, faded image on an out-of-the-way cave wall. Artistic styles include paintings, rock engravings (petroglyphs) and beeswax motifs. It's hard to date rock art but scientists believe some examples to be over 30,000 years old.

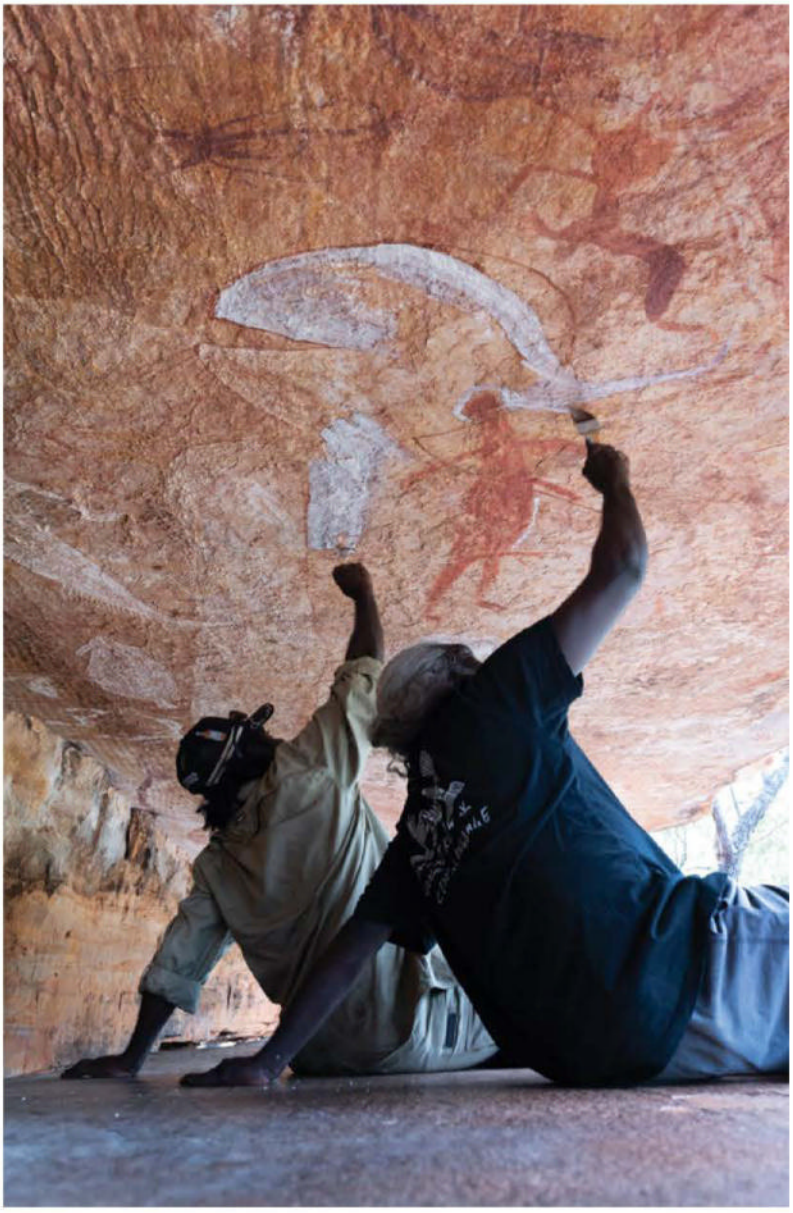
Rock-art hotspots around the country include Arnhem Land in the NT, and the Kimberley and the

"That's what happens when you leave your country. The country is all alone and the story will fade away."





Opposite top left: Terry (in red) and Conrad (in black) Maralngurra discuss the process of repainting Naworo; others contributing knowledge include Warddeken Land Management rock art project manager Claudia Cialone (opposite below). Terry's grandson Festo (opposite top right) takes a relaxed approach. Once work is underway, fine detail is applied with manylk (above) – a stiff brush made from the stem of spear grass – while white areas are filled in (right) with modern paintbrushes to save time. Clan members participating include (top right) Terry's son Robbie, and Clifton Namundja Nagurrgurrba (right, at left).



Pilbara in WA. The stone country is particularly rich; it's estimated there are three or four art sites for every 10 sq. km of rocky terrain – potentially more than 40,000 sites in total. Most art is in or near areas where Bininj have lived for thousands of years and while some sites are specific to men or women, most are communal. Bininj know rock art paintings as bim, an abbreviation of kunwarddebim (gwart-ay-bim), a word in the Kunwinjku dialect. The art usually serves a purpose – to educate children about the natural and spiritual world, describe food sources, provide a warning, delineate clan boundaries, tell stories about important events or to simply celebrate life.

Of particular interest in the stone country is art from the period when Bininj came into contact with people from other cultures – Macassans (seafarers from modern-day Indonesia) and Europeans. It is one of the best records of first contact between cultures in the country.

Some galleries hold paintings of white, ghostly figures (Europeans) smoking pipes or carrying rifles

atop creatures that resemble massive macropods (horses). These 150-year-old illustrations sit alongside – and in some cases are painted over – bold, naturalistic figures that date back thousands of years.

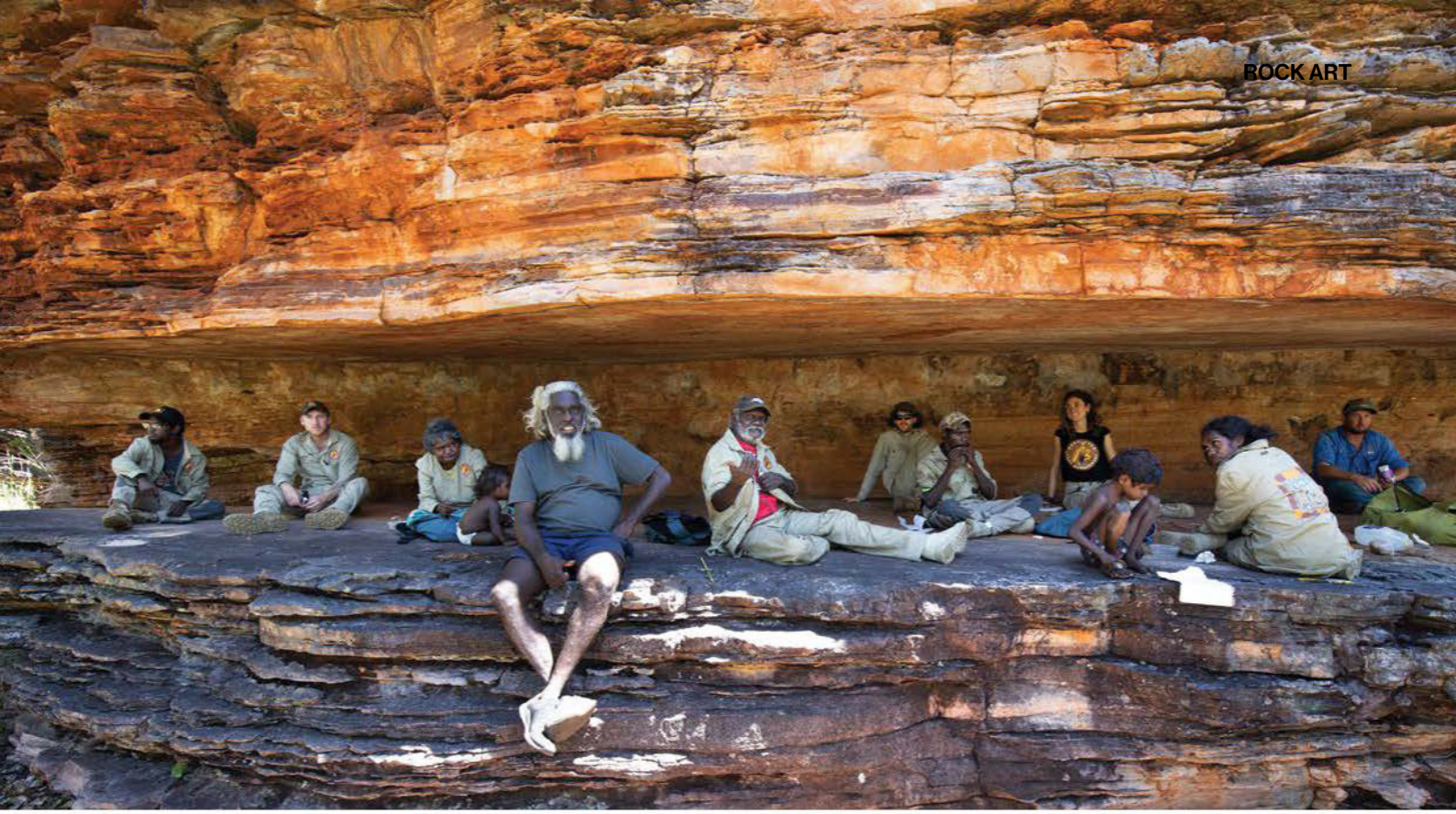
In the past, rock-art research has primarily been the domain of anthropologists and archaeologists employed by tertiary institutions. Their findings are built on the raw materials of traditional knowledge (interviews and documentation of conversations with traditional owners) and photographic images and artefacts taken from sites.

These materials often remain with institutions where they were archived, studied further by academics or used by governments to justify the protection or exploitation of an area. Rarely do the data or materials return to a community in any form other than a research paper or government document.

Rock-art research grants are largely directed through the Australian Research Council, which allocates funds to researchers at Australian universities. Grants to study any aspect of rock art are rarely given to Indigenous organisations; however, Bininj have now taken charge of research on their own country.

In 2010, Aboriginal elders from the Warddeken and Djelk IPAs established the Karrkad-Kandji

Josephine Maralngurra (below, centre) discusses the painting with son Robbie while Conrad and Terry look on. The Traditional Owners decided to paint around some of the newer, red-ochre paintings rather than over them as respect to their forebears. The work used traditional colours: kunrodjbe, red ochre, for the outline; and for the main body delek, white clay, shown at right being mixed by Clifton. Cialone (opposite below) watches Daluk ranger Tinnesha Narorrga Nabulwad apply detail to Naworo's six toes. The rock shelter (opposite top) can easily accommodate up to 20 people.

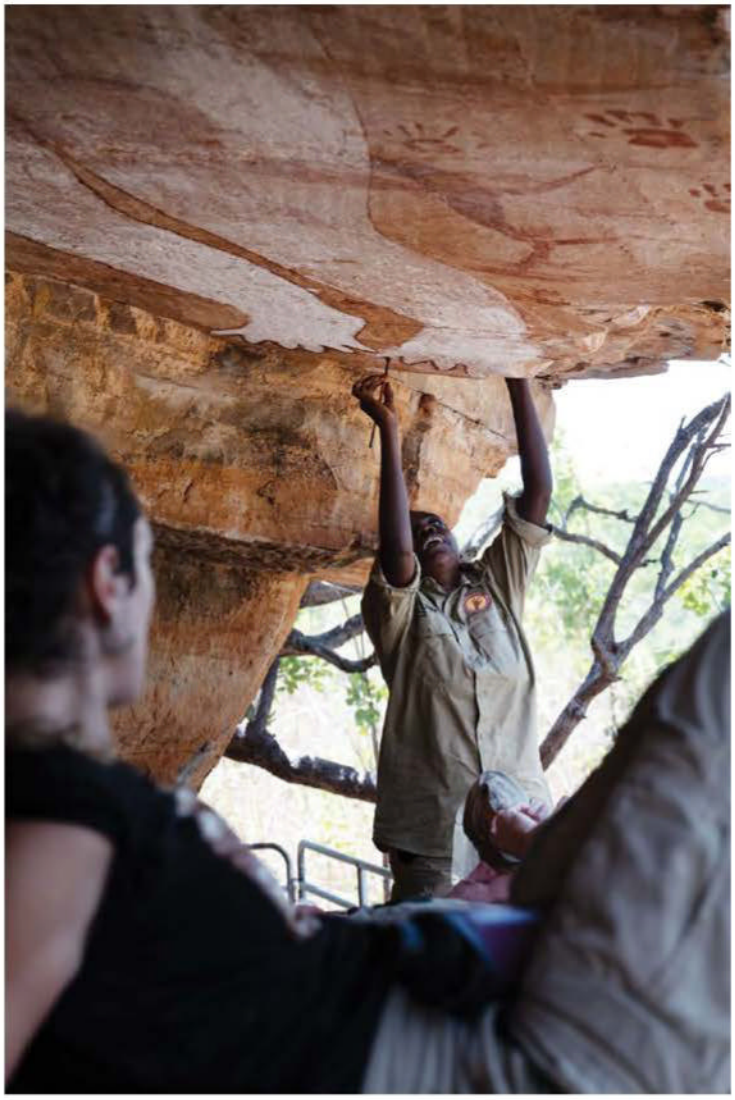


"We also want to share the stories but we want to take control and have legal ownership of the knowledge."

Trust to seek alternative sources of funding for land management and cultural projects. KKT approaches Australian and international philanthropic organisations and individuals to raise millions of dollars. This has enabled elders, through their land management organisations, to employ specialists who work with and train Bininj rangers to locate, record, preserve, maintain and study sites and artwork.

Dr Claudia Cialone, the current rock art project manager, has worked for Warddeken Land Management for five years; three years ago she was joined by project officer Chester Clarke. Cialone is a fluent Kunwinjku speaker who studied at the Australian National University to gain a multidisciplinary PhD in linguistics and spatial navigation; her thesis was based on field work in the Warddeken IPA in 2015–17. Clarke studied archaeology at Flinders University in SA.

They are two of several scientists employed by WLM to help manage different aspects of the IPA. Cialone and Clarke live and work between three outstations – Kabulwarnmyo, Manmoyi and



"Culture and ecology is one and the same for Bininj because it is a culture that is embedded in ecology."

Mamadawerre – looking for and recording bim in remote areas with Indigenous rangers.

"We employed these people because we want them to help us preserve the stories through balanda ways," says Conrad Maralngurra. "We also want to share the stories but we want to take control and have legal ownership of the knowledge. We want to maintain, preserve and protect it for the benefit of our own country and people."

Cialone's work with Bininj includes providing logistical support to take people out bush, usually in 4WDs or helicopters; to teach technological skills to record art using cameras, tablets and GPS devices; and to help with cultural and linguistic recordings to gather the stories of the motifs.

"We work together on ways to create a database to keep all that information safe for future generations and establish an element of accessibility for elders who cannot get to those sites," she says.

"There are opportunities for Bininj in land management roles in connection to cultural heritage, through extending academic qualifications and fulltime work. Culture and ecology is one and the same for Bininj because it is a culture that is embedded in ecology."

The painting of Naworo at Kudjekbinj is a short helicopter flight from Mamadawerre, an outstation with a seasonal population of 30–50 people. The Goomadeer River flows nearby and the settlement is a base for Warddeken rangers.

"The Naworo site is fantastic," Cialone tells me. "The rock in the lower position would have held a lot of people sitting on it and I have never seen a painting so long. At 9.5 metres it may be the longest rock-art painting in the whole of Arnhem Land.

"It is certainly a beautiful place and is clearly not an opportunistic site. People – maybe a family or small community – lived there for a long period. Bininj would call it kuwaddakuken (gwarta-gugen), a real – as in culturally significant – home.

"This site is also special because there are [human] bones in a cave at the front of the site and there are bones at the back, so it is the combination of one of the longest paintings in Arnhem Land, plus a double burial site."

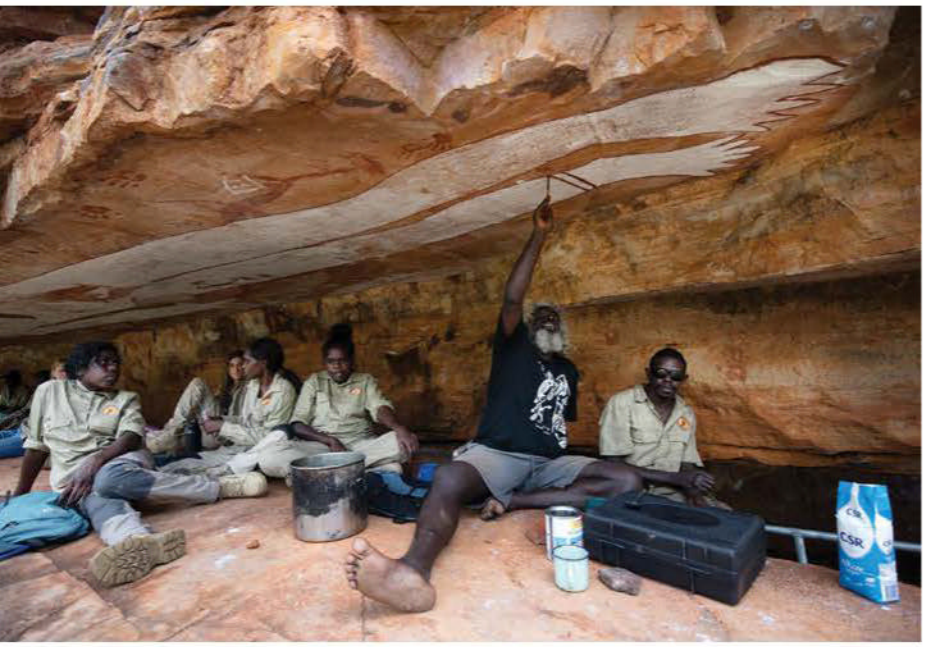
Repainting rock art can be controversial among Bininj, and Traditional Owners have differing views, often depending on the subject matter.

"Repainting rock art can be a tricky concept," Cialone says. "We have discussed this at Warddeken Board level; in European terms such process can go under the heading of restoration, which is part maintenance and conservation to return a work of art to its original condition.

From the air, the shelter site (above left) appears to be a narrow slit in a massive sandstone boulder; even from the ground, the image of Naworo is extremely well hidden, but known to the Ngalngbali clan for thousands of years. Clan members such as Robbie (top left) and Tinnesha (above, and opposite bottom left) spent three days on site renewing Naworo, an effort that culminated (opposite top) with a smoking ceremony to cleanse the site and welcome the ancestor back to country.

"Some Traditional Owners seem to be of the idea that if the painting is disappearing, it means the spirits of the land would have wanted it, and we have to let it disappear. Some others think that if we are not going to the site anymore and we don't live there anymore and if we don't do anything for it this will disappear, taking with it not only the visual but all the stories associated with it and so we will not have anything to pass on to the next generations other than photos of the past. We all know that the best intergenerational exchange of knowledge happens on country rather than [looking at] photographs in an office."

In the case of Naworo, the decision to renew was made by senior custodians Terry and Conrad Maralngurra. They also wanted many members of the Ngalngbali clan to be involved in the project: Terry was accompanied by his wife Josephine, son Robbie and his wife, Selisa Burunali, and their two children Velina and Festo. Rangers cleared vegetation from around the site to ensure fire would not damage the painting and secured panels to keep feral animals such as pigs and buffalo at bay.



"Empty country is the biggest threat to culture. This was a way to take three generations out there to tell stories."

Members of the clan carefully and slowly brought Naworo back to life over three days in early May, frequently lying back on their elbows to examine their work. Five-year-old Velina Maralngurra scrambled around the rocks and her one-year-old brother slept peacefully on the cool sandstone. During the process Conrad and Terry sang songs associated with Naworo and his travels, and at the end they cleansed the shelter with smoke.

"We had three generations present," Cialone says. "This is important because the rock-art project is not just a conservation exercise or an archaeological endeavour; it is an effort that Warddeken and Bininj are putting in to overcome the risk of empty country.

"Empty country is the biggest threat to culture. This was a way to take three generations out there to tell stories, so it's not just the science of restoration of the site. There is also the importance of taking people back on empty country and keeping that lore alive."

Much as their ancestors would have done during the painting process, young Daluk (female) rangers (above right) decorate their faces – and Cialone's – with kunrodjbe. In one of the work's final moments (above), Conrad Maralngurra reaches up with a manylk to etch a detail. With the work finished (opposite), Conrad uses one of his thongs to keep time to a song that celebrates the renewal of Naworo, as other clan members relax and bask in their work.

At the end of the project, Terry and Josephine's grandchildren and other young Bininj gather on the sandstone slab and gaze up in awe. There, in the spirit ancestor's renewed presence, Terry tells them Naworo's story.

"Before I was ever born, this fella here built this place," he says. "Naworo was a creative man, he made heaven and earth. He came all the way from Goulburn Island [in the Arafura Sea] with his two wives. They travelled all over Arnhem Land together but he got angry with those two and left them in a cave on a high mountain near Gunbalanya.

"He travelled inland towards here passing Goomadeer [River] right up to Mamadawerre. Near Kudjekbinj he chopped off his right arm to use like a fighting stick; it was very long and heavy, and as he dragged it along it made a creek all the way to the old camp near Mamadawerre.

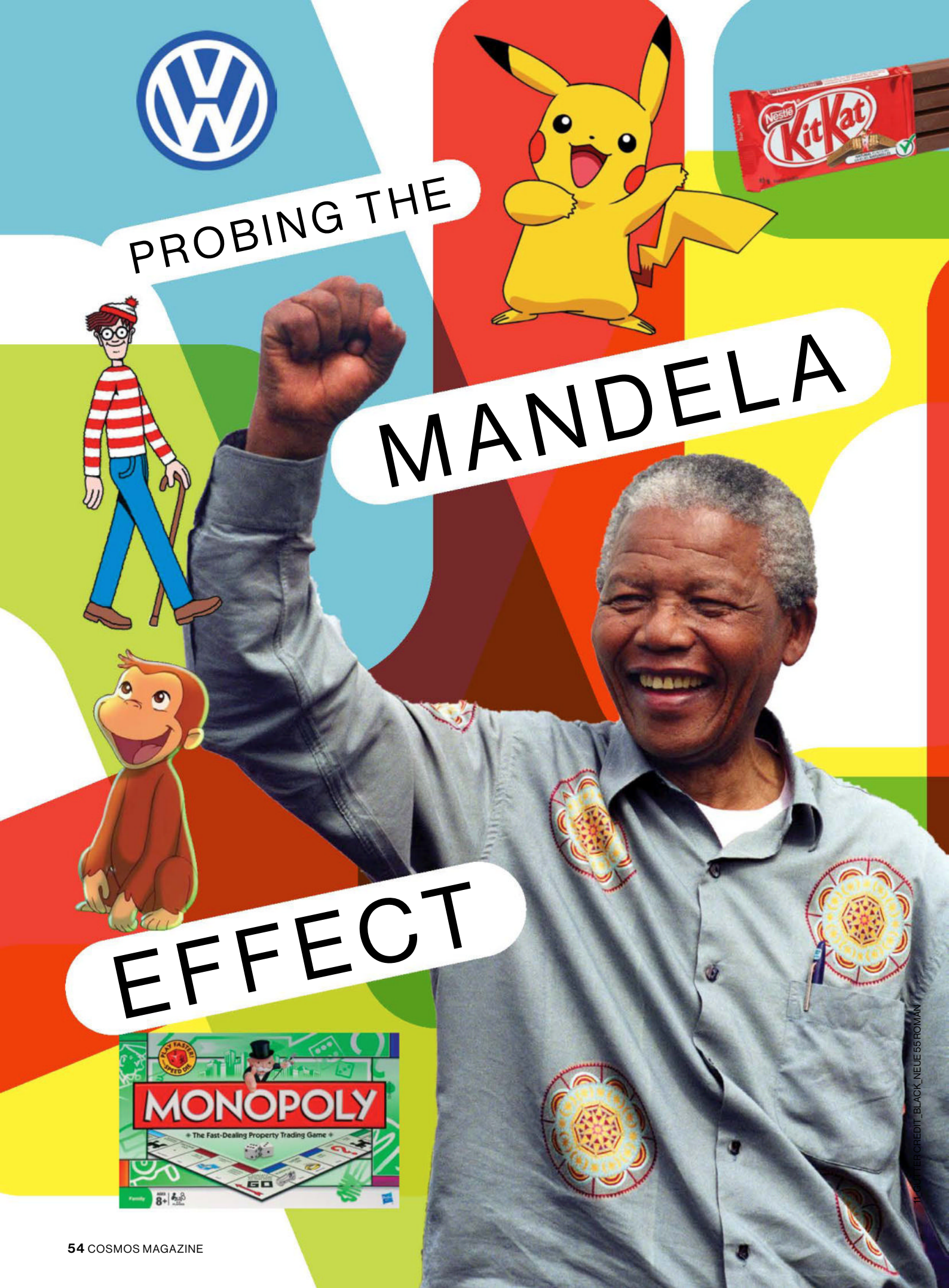
"He went upstream alone with his arm and made a creek up to the place where we are now. Suddenly he sees all the rocks, he looked around and decided to put himself here. All he had to do was blow on that rock to cover himself, the one we are sitting on. So we are sitting down here and he is underneath. His spirit – that white drawing you see above – is his spirit.

"Every single day if you go and check, his head is different – sometimes bird, or frog, or buffalo – but different every day like the animals around here. In the old days when people were living in this country they would visit Naworo a lot. He would reveal himself to them by dreams and talk to them through songlines, celebrations and help them find bush tucker, so the stories would go on and on and on.

"That's the end of the story. Not really long one. But important."

DAVID HANCOCK is based in Darwin. His last story, about Top End marine megafauna, was in Issue 97.

PROBING THE MANDELA EFFECT



How is it possible to think you're sure about something, only to learn that your memory's let you down, and you were wrong all along? **Denise Cullen** investigates an odd, and little-understood, phenomenon.

Board games, movies and former South African presidents. Nothing – and no one – is spared when it comes to false memories.

(MONOPOLY) IVANASTAR; (KIT KAT) ROBTEK; (MANDELA) PER-ANDERS PETTERSSON/GETTY IMAGES

Imagine learning about a famous person's death, watching footage of the funeral, and listening to the eulogies – then, decades later, finding out that this person had been alive all along.

This was the scenario confronting Fiona Broome in 2009 when she shared her memory online, then subsequently learnt that Nelson Mandela was still alive.

Broome, a paranormal researcher, had a distinct memory of the human rights activist and Nobel Peace Prize winner dying in prison in the 1980s.

"I thought I remembered it clearly, complete with news clips of his funeral, the mourning in [South Africa], some riots in cities and the heartfelt speech by his widow," she wrote on her website, in a post since removed.

As history records, Mandela died aged 95 – a free man and revered former South African president – in 2013.

Broome would have been willing to chalk it up to a glitch in her memory. But after discovering that many others shared the same memory, she decided it was instead a glitch in the matrix – a sign consistent with the many-worlds theory of quantum physics that there was a parallel universe in which Mandela had, indeed, died in prison in the 1980s.

Since then, many other examples of what's become known as the Mandela Effect – or shared false memories – have emerged.

Common examples include that Rich Uncle Pennybags – aka the Monopoly Man – wears a monocle (he doesn't), that Pokémon character Pikachu has a black-tipped tail (it's yellow) and that there's a hyphen in KitKat (there isn't).

Geographically, some folks swear that there are 51 or 52 states in the United States (there are 50) or that New Zealand is located north-east of Australia (it's south-east).

Cinematic examples include the Evil Queen in *Snow White and the Seven Dwarfs* saying "Mirror, mirror on the wall" (it's actually "Magic mirror on the wall"). And who can forget the chilling moment in *The Silence of the Lambs* when Hannibal Lecter first meets Agent Starling and says, "Hello Clarice"? Thing is, it never happened.

Misremembering the finer details related to board game mascots, fictional characters or logos might sound inconsequential. Yet the Mandela Effect has spawned a fertile field of psychological research seeking to uncover why people develop false memories – and why, when they do, they are along much the same lines.

Wilma Bainbridge, who works in the Department of Psychology at the University of Chicago, has been interested in the workings of human memory since she and others discovered that people are surprisingly consistent in what they remember, forget and make false memories about.

In 2011, Phillip Isola and some of his colleagues at the Massachusetts Institute of Technology (MIT) identified that memorability was a stable property of an image shared across different viewers.

Presenting at the annual Conference on Computer Vision and Pattern Recognition (CVPR), they built one of the first computer vision systems that sought to predict the memorability of different images.

They also provided some of the first glimmers that low-level visual attributes of an image – such as its bright colours, or distinctive edges – cannot alone account for its memorability. Similarly, aesthetics (visual appeal), interest (how likely people are to be drawn to or interact with an image) or saliency (the area which draws people's eye focus first) are insufficient to unlock the keys to memorability.

While completing her PhD at MIT, Bainbridge, Isola and MIT colleague Aude Oliva drew on a 10,168-image database of facial photographs to see if the same intrinsic memorability was found in human faces.

Their research, published in the *Journal of Experimental Psychology*, found that some faces were consistently remembered or forgotten – and that this couldn't be fully explained by attractiveness or other perceived character traits such as 'trustworthy' or 'boring'.

Bainbridge says it was Isola's paper in 2011 and hers in 2013 that launched the burgeoning field of memorability. Since then, 845 scientific papers have cited the two papers.

Currently on maternity leave after having twin girls, Bainbridge told me via email that she was originally inspired to probe the visual Mandela Effect because of how pervasive discussions were online about people having the same false memories. But no memory research had then investigated this intriguing phenomenon.

In a recent article in *Psychological Science*, Bainbridge and her colleague at The University of Chicago, Deepasri Prasad, explored the visual Mandela Effect for the first time.

This is the tendency for people to consistently misremember characters or logos from popular culture – things that were, in fact, designed to be memorable.

Over a series of experiments – using icons such as the Monopoly Man, Pikachu, Curious George, the Volkswagen logo and Waldo from *Where's Waldo* – they provided the first experimental confirmation that the visual Mandela Effect exists. (*Where's Waldo?* is known as *Where's Wally?* in Australia. The discrepancy isn't an example of the Mandela Effect. It arose because publishers believed 'Waldo' would better resonate with North Americans.)

"RECALL IS A MORE ACTIVE AND EFFORTFUL PROCESS THAN MERE RECOGNITION"

In the first experiment, they presented 100 adults with images of 22 characters, 16 brand logos and two symbols, and made two altered images of each.

For instance, they modified Curious George by adding a thin tail in one image and a bushy tail in the other.

Research participants viewed all three images and had to choose the correct one.

The results indicated that seven out of the 40 images elicited shared – and specific – false memories.

In the second experiment, they used eye-tracking methods to see if there were differences in the way participants looked at the images they correctly identified, versus those they got incorrect.

"We found no attentional or visual differences that drive this phenomenon," Prasad and Bainbridge wrote.

In the third experiment, the researchers scraped the top 100 Google Image results for each of the seven images to see if previous exposure to non-canonical (incorrect) versions might explain it. But they concluded that there was "no single unifying account for how prior perceptual experiences could cause these visual false memories – which had previously elicited the visual Mandela Effect – to occur".

The fourth experiment involved having participants draw the images, given that recall is a more active and effortful process than mere recognition.

Some participants viewed the canonical (correct) images prior to being required to reproduce them, while others, who'd flagged that they were already familiar with the images, did not.

One-fifth of all images drawn by the former group, and about half of those drawn by the latter group, showed characteristic Mandela-Effect-type errors. For example, the Monopoly Man frequently appeared with a monocle, while Waldo was often depicted sans cane.

The common production of such errors during both short- and long-term recall suggests there's something intrinsic to these images that leads to people generating the same sorts of fallacies – but Bainbridge says that researchers are only just beginning to probe what that might be.

Her laboratory is concerned with broader questions about why some images are intrinsically memorable.

"Even though we've all lived different lives, there are some pictures that most people remember and some pictures that most people forget," she explains.

Interestingly, when people view an image, high-level visual and memory areas in their brains show a sensitivity to its memorability – regardless of whether they consciously remember seeing it or not.

Several functional magnetic resonance imaging (fMRI) studies, including one conducted by Bainbridge and her colleague Jesse Rissman of the University of California Los Angeles and published in *Scientific Reports*, have demonstrated distinctive brain activation patterns (neural signatures) when memorable images are viewed.

These processes take place outside conscious awareness, suggesting they occur automatically.

Humans aren't alone in this, with research led by Nicole Rust at the University of Pennsylvania and published in *eLife* in 2019 identifying similar patterns in rhesus monkeys who completed visual memory tasks.

In a 2022 paper published in *Computational Brain & Behavior*, Bainbridge and her then University of Chicago master's student Coen Needell wrote that they had developed a deep learning neural network that can predict people's memories.

"We've recently developed a web tool called ResMem using deep learning artificial intelligence where you can upload an image and it will tell you the per cent chance someone will remember that image," Bainbridge says. "Anyone can try it out with their own photos."

Recent work shows that the images people remember or forget can even be used to identify early signs of Alzheimer's disease.

Research published by Bainbridge and colleagues in *Alzheimer's & Dementia: Diagnosis, Assessment & Disease Monitoring* in 2019 found that a small, specific set of images reliably differentiated people with mild cognitive impairment (MCI) or subjective cognitive decline (SCD) from healthy controls.

Using data drawn from the DZNE-Longitudinal Cognitive Impairment and Dementia Study (DELCODE), an observational, longitudinal memory clinic–based study across 10 sites in Germany, Bainbridge and colleagues analysed the memory performance of 394 individuals.

Each participant viewed a randomly selected subset of 88 photographs from a total pool of 835.

The performance of 193 healthy controls was compared to 136 participants with SCD – elderly individuals who self-report a decline in cognitive abilities but don't yet meet clinical thresholds – and 65 participants with MCI: elderly individuals who show early clinical signs of cognitive decline, but are not yet at the level of Alzheimer's disease.

(Bainbridge notes that Alzheimer's disease is more severe than MCI, which is more severe than SCD; however, it is possible to have MCI or SCD and never end up developing Alzheimer's disease.)

The researchers found that there was a lot of overlap in what the different groups remembered and forgot.

However, there was a small subset of images that were highly memorable to healthy controls, but highly forgettable to those with mild cognitive impairment or subjective cognitive decline.

A subset of as few as 18.3 images could distinguish between the two groups.

In this way, the intrinsic memorability of images might ultimately pave the way towards quicker, easier and more reliable diagnostic tests of precursors to Alzheimer's disease.

Though this research is not the focus of Bainbridge's laboratory, work in this area is continuing, with the promise of some yet-to-be-published data suggesting that these more diagnostic images also better tap into the underlying brain pathology in those with MCI.

"We're now interested in creating a neural network tool that can predict your chance of making a false memory to an image – and then, theoretically, you could make images that cause lots of false memories," Bainbridge explains. "These next steps are still in very early stages, though, and sadly, we don't really have anything yet [on what features may prompt false memories]," she says. One goal of the research is to make the neural network tool available to any scientist who wants to study what makes something cause false memories.

Bainbridge's research on memorability has potential applications for further research as well as education, which may be enriched, for example, with textbook images or infographics that are more likely to stick in students' minds. The findings are also likely to enhance clinical practice, given that memory problems are the most common cognitive deficits in dementia.

Bainbridge says those experiencing dementia typically benefit as a result of specially designed environments or tools to aid their memory – for example, memorable cues to help them remember to take essential medication.

The study of false memories also has weighty implications for criminal defence, given that some people might be wrongfully identified as suspects just because their faces cause false memories more easily.

"You'd want to make sure to control for that when choosing a line up," Bainbridge says.

"It's pretty amazing to think about how our brains can build up vivid memories of images that don't really exist and that we've never seen before."

Shared false memories can be so convincing that we never think to question their veracity. "Magic mirror on the wall", anyone?

FROM TOP: ORION FILMS; WALT DISNEY PRODUCTIONS.

DENISE CULLEN is based in Brisbane. This is her first story for the magazine.

Compact and easily overlooked, bar-tailed godwits make the longest known nonstop flight of any animal on Earth. **Drew Rooke** reports on the research that led to the amazing feat's discovery – and that is changing much of our understanding of the science of these epic crossings.

Birds without borders

ROCKPTARMIGAN/GETTY IMAGES

BOB HILSCHER/GETTY IMAGES

22 December 2022

The large tinnie cruises the calm waters, charting a course from the boarding jetty, past moored yachts and waterfront mansions that crowd the shoreline of Georges River at Taren Point, on Dharawal country in suburban southern Sydney. A veil of cloud softens the sunlight and a gentle sea breeze keeps this late-December morning's heat in check.

I'm seated at the bow of the boat, which gathers speed after it passes beneath Captain Cook Bridge, where the river widens into Kamay/Botany Bay. In the distance I can see Sydney's CBD skyline and the towering red-and-yellow cranes of Port Botany that look like giant steel giraffes.

From the stern, captain and coxswain Robert Dixon looks across the water through warm brown eyes shielded by sunglasses. The wind ruffles his long-sleeved polo shirt and threatens to rip off the Akubra pulled down over his short black hair.

Dixon knows this area well. An Environmental Officer from Georges Riverkeeper, a catchment management group that coordinates environmental projects on behalf of eight local councils, he's been in charge of the group's long-running monthly shorebird and waterbird survey for the past three years. This is why he's out today with three volunteers. It's currently high tide, ideal for our purposes. As Dixon explains in his deep, gentle voice: "That's when the birds congregate."

Travelling around the bay over the next hour or so, a pencil dangling from his mouth, Dixon carefully manoeuvres the boat around submerged hazards and reaches over the side to collect rubbish that we pass in the water. At each survey site, he kills the outboard motor and keeps enough distance from the shoreline to avoid disturbance. He records the 18 species of birds we see – pied cormorants, little terns, red knots – on a count sheet secured in a clipboard on his lap. At one site on the bay's southern shore, he's surprised to find only a handful of pied oystercatchers perched on a row of wooden posts protruding from the water. "There were a lot more shorebirds using this area this time last year."

The site with the most birds is a roughly 350-metre-long squiggle of sand called Towra Spit Island. Of Botany Bay's scant shorebird habitat that's endured since Captain James Cook moored *Endeavour* here more than 250 years ago, this is the most important: unlike much of the other surviving habitat, it's predator-free and largely undisturbed by human activity. But it is slowly disappearing, prey to changes in wave energy and sediment deposition caused by major development projects throughout the bay.

Hundreds of birds roost on the island; most are annual migrants only recently arrived from very far away – further, in fact, than most of the planes coming in to land at the international airport just north, across the bay.

The birds that have made the most extreme journey to get here are the 200 bar-tailed godwits (*Limosa lapponica*) – more specifically, *baueri*, one of six subspecies – that are packed together on the island's northern edge. These champions of long-distance migration have been here for about two months. Today, they're waiting for the tide to

drop so they can feed on the crabs, yabbies and worms that live in the few sand and mud flats that remain in the bay. Individuals with streaked greyish-brown non-breeding plumage are camouflaged well against the sand; a long, graceful, upturned bill – pinkish at the base, with a black tip – protrudes from a small, white head.

The flock is quiet and calm. Apart from a few birds squabbling for space, most are standing still on the water's edge – many on only one of their spindly, dark grey legs – unbothered by the small waves washing over the sand. Some have their heads twisted backwards, bills buried in between folded wings. Others scratch under their neck with clawed toes and ruffle their feathers as if waking from a nap. They are scrawny, their 40-centimetre-long bodies carrying very little fat.

But although these birds might not look like ultra-marathoners – at least not at this time of year – one of their kin has just broken the record for the longest nonstop flight of any animal on Earth, clocking more than 13,000km on a globe-spanning journey from the far north to the far south.

The decades-long research that led to this discovery calls into question much of our historical understanding of migratory birds – and animal biology more broadly. It demonstrates that these small but sturdy creatures aren't just like programmed machines that possess innate powers of endurance and navigation. The truth of their annual epic is far more complicated, and far more fascinating.

By studying these epic there-and-back-again journeys, shorebird researchers are drawing lines of global ecology across the planet. Billions of birds annually renew connections to vastly separated places and the species they depend on there, from the moss of the Alaskan tundra to the worms and molluscs of Kamay/Botany Bay (above) or Pūkorokoro/Miranda in Aotearoa New Zealand (previous page).

Avian migrators are birds of no nation – even the most strictly controlled ones. They live a life of joined dots, constant movement and journeys spanning entire oceans and continents. Their urge to move is so irresistible that in the lead-up to their scheduled departure (and when they are held in captivity) they experience *Zugunruhe* – German for migration anxiety. They become restless; they start to flutter their wings, hop in place and call loudly. Many suffer sleeplessness.

For a long time, the coming and going of particular birds baffled humans and hatched some farcical theories about their seasonal movements and extended absences. Aristotle, for example, believed that migratory birds didn't actually leave a place but transformed into different species, while Swedish archbishop Olaus Magnus theorised in 1555 that swallows hibernate in the mud at the bottom of lakes and streams. A century later, English minister Charles Morton suggested some birds migrate to the Moon for the winter.

Instead of hypothesising about destinations, early Polynesians decided to follow the huge flocks of bar-tailed godwits they saw flying southward over the Pacific Ocean each year. A source of wonder, the sight of these birds was believed to point to land beyond the horizon, for it was clear from

DEB ANDREWS

their shape and size that they weren't of the sea. In fact the Māori, who know the bar-tailed godwit as *kuaka*, credit it for inspiring and guiding their ancestors on their seafaring voyage from northern Polynesia to their new home of Aotearoa, later New Zealand, roughly a thousand years ago.

Revered in Māori culture, the kuaka is also now loved by many others in Aotearoa New Zealand, the birds' principal stopover site in the Southern Hemisphere. When the first of several thousand bar-tailed godwits arrive there every September, they're welcomed by the ringing of cathedral bells in the South Island town of Whakatū/Nelson. When the birds are due to leave from late February, hundreds of people attend a ceremony at the Avon-Heathcote estuary in Ōtautahi/Christchurch to say goodbye to the 1,500 to 2,000 godwits that visit that particular site every year.

Their urge to move is so irresistible that in the lead-up to their scheduled departure they experience *Zugunruhe* – migration anxiety. They become restless; they start to flutter their wings, hop in place and call loudly.

"We have a little barbecue and then take people in groups to the edge of the estuary where we have telescopes set up, so everyone can get a really good look at the birds," says Tanya Jenkins, manager of the Avon-Heathcote Estuary Ihutai Trust, who helped establish the ceremony in 1999. "This year, the youngest person who came was in a pram and the oldest was 93 years old."

The ceremony gets bigger every year, and it can occasionally get quite emotional. "I've actually seen people in tears because they are so amazed by the movement of these birds," says Jenkins.

It's largely because of the work of people like Robert Gill that others have recently learnt to love this little bird. For the past 40 years Gill has worked as a wildlife biologist at the US Geological Survey's (USGS) Alaska Science Centre. Over a video call from his home – which is decorated with framed photographs and wood carvings of shorebirds – he tells me that he first encountered bar-tailed godwits in the Arctic summer of 1976, when he took a job on the Alaska Peninsula assessing shorebirds to better understand the impact of the expanding gas and oil developments along the US Pacific coast.

"I'd never seen a bar-tailed godwit in my life," he says. "And suddenly, I'm in a setting where there are thousands of them."

As Gill, fascinated, observed the birds over the course of their breeding season, he noticed strange changes in their appearance and behaviour. They gained huge amounts of fat, for example, and their bright, cinnamon plumage faded to a dull light grey. They also started to become much more active, flying together in large flocks.

Then, one clear morning after several days of heavy storms, Gill woke up to find that the birds had all disappeared. "I scratched my head thinking, 'Where did they go?'"

Gill went hunting data. He trawled through references in serial publications; field notes from earlier scientific expeditions and surveys; ornithological collections from museums in places like Australia and Hawaii; and unpublished databases maintained by ornithologists. He discovered the bar-tailed godwits he had seen breeding in Alaska flew annually to Aotearoa New Zealand and eastern Australia. From there they travelled to the intertidal mudflats of the Yellow Sea region of East Asia, and then back to Alaska.

But this raised another, even more intriguing question: what path did these birds fly to reach these distant places?

Gill's initial hypothesis was that they island-hopped from Alaska across the Pacific or perhaps followed Asia's coast to travel the more than 11,000km to their antipodean destination – paths with plenty of refuelling sites and navigational landmarks. But research that he and many others around the world conducted over the following decades proved that the birds took a different route, one that was seemingly incomprehensible.

"Everyone needs a passion in their life," says Adrian Riegen, who formed the New Zealand Wader Study Group in 1994 and continues to survey shorebirds after a hard day's work building houses. "And shorebirds are my passion."

Riegen first became interested in birds in the late 1960s as a twitcher, "racing after the rarities", but quickly realised "there's more to birdwatching than just ticking off new species". Now, he's one of what he calls the "unpaid professionals": citizen scientists who have worked over decades and countries to survey and band bar-tailed godwits along their entire migratory pathway.

"If you spend 50 years studying these birds, you build up a huge amount of knowledge about them, even though it might not be published."

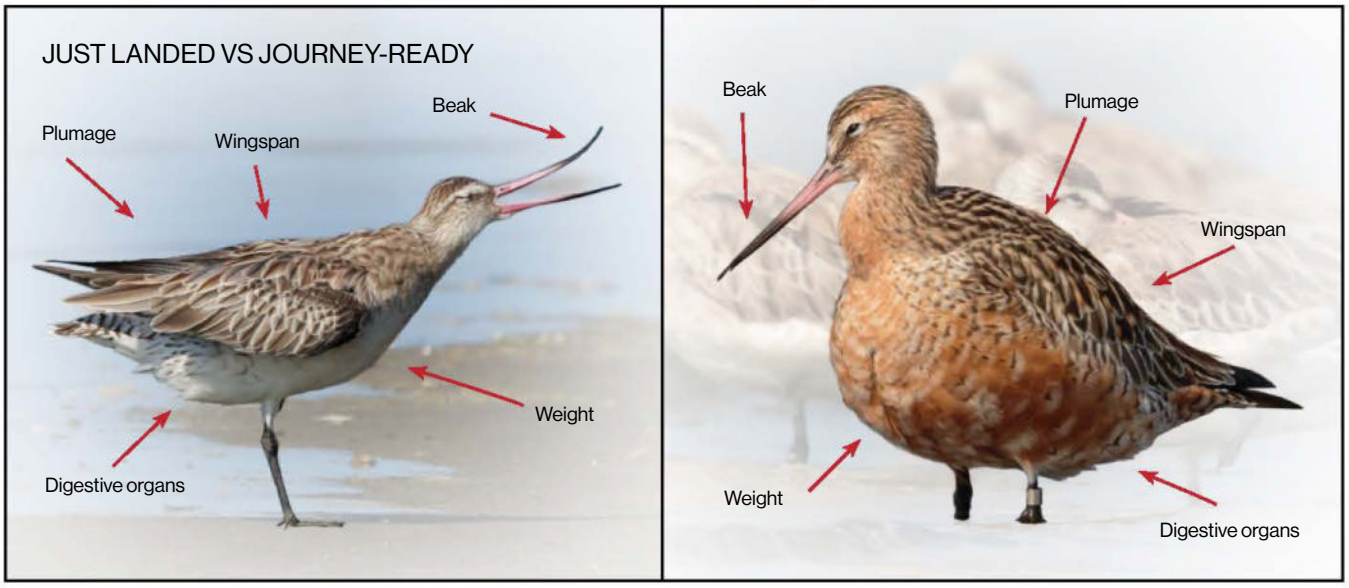
The knowledge that people like Riegen gathered in the late 20th century proved invaluable, particularly in building a better understanding of the precise timing of the bar-tailed godwit migration. Largely based on this knowledge, paid professionals like Gill started to investigate an idea first proposed by ornithologist Dick Sibson in the mid-1980s: that bar-tailed godwits fly nonstop from Alaska to their destinations, directly across the Pacific Ocean.

This idea gained substantial weight following a fortunate and incredible discovery about the biology of these birds.

Shortly before midnight on 19 October 1987, a large flock of juvenile bar-tailed godwits crashed into a radar dome on a military base near Cold Bay, on the Alaska Peninsula. The birds had only just set out on their epic flight to the Southern Hemisphere. Two died on impact; seven were badly injured and subsequently euthanised.

Luckily, one of Gill's colleagues worked at the military base and had the wherewithal to not only collect and measure the birds but preserve them in a freezer. Subsequent compositional analysis revealed that they had an average total body mass of 367 grams – 55% of which was fat. This didn't surprise Gill; from field observations, he knew the birds were gorged with fat prior to departing

While it's tempting to compare migratory birds to marathon runners, the radical changes that birds make to their bodies in order to fly vast distances leaves humans in the dust – no marathon runner doubles their weight or reduces the size of their organs. Since the birds essentially live on the flyway, they are constantly recovering or preparing, and so are in a state of perpetual physical transformation.



IMOGEN WARREN X2/GETTY IMAGES

DIANA ROBINSON PHOTOGRAPHY/GETTY IMAGES

"Based on knowledge gathered by citizen scientists, paid professionals started to investigate the idea that bar-tailed godwits flew nonstop from Alaska to their destinations."

Alaska. What did surprise him was the abnormally small size of the birds' stomachs, gizzards and livers – and the abnormally large size of their wing muscles and hearts, compared to those of non-migrating bar-tailed godwits.

Unsure of what to make of these results, Gill shared them with a colleague.

Although it was nearly 30 years ago, Theunis Piersma, professor in Global Flyway Ecology at the Conservation Ecology Group at the University of Groningen, in the Netherlands, still remembers the moment that Gill handed him a yellow manila folder with the results of the analysis.

"It was like *boom*," Piersma tells me on a video call from his second office at the NIOZ Royal Netherlands Institute for Sea Research, where he can watch migratory birds flying over the Wadden Sea. "It opened my mind."

The research showed that migratory shorebirds aren't, as US biologist Eugene Odum had previously argued, like planes that have a constant structure but variable fuel load. Rather, not only are the birds able to gain huge amounts of fat to use for fuel, but their bodies undergo a significant restructure to ensure this fuel is used most efficiently.

As Piersma and Gill wrote in their 1998 paper "Guts Don't Fly": "The small size of the nutritional organs of extremely fat bar-tailed godwits... is consistent with the suggestion that it is unprofitable and energetically too expensive to carry a digestive machinery over thousands of kilometres of open ocean."

Piersma, Gill and colleagues gathered more evidence to support the idea that bar-tailed godwits fly nonstop across the Pacific by examining large-scale weather maps; building flight simulation models; and trawling through more historical observations of the birds across the world. In 2005 they published this evidence in a landmark paper titled "Crossing the ultimate ecological barrier". It prompted disbelief – and some scepticism – within the scientific community. But new technology soon provided indisputable proof.

On 17 March 2007, an adult female known as E7, who was carrying a surgically implanted 26-gram battery-powered satellite transmitter roughly the size of a 20-cent coin, departed the Firth of Thames in Aotearoa New Zealand. After flying continuously for seven days and nights across 10,200km, she arrived at the Yellow Sea. Five weeks later, she took to the skies again, flying 7,200km over five days to her breeding grounds on the Yukon–Kuskokwim Delta in Alaska. Then, in the early hours of 29 August, she departed Alaska and spent the next eight days travelling nonstop over the Pacific Ocean to a bay south-east of Tāmaki Makaurau/Auckland.

Decades of work by biologists like Robert Gill (above) have slowly revealed the godwit's story. Remarkably, most juveniles make their first migration flight without adult guidance. The male B6 (top left) was first leg-banded and fitted with a 0.5g VHF transmitter in western Alaska in July 2022. A few days later the VHF device was replaced with (top and above right) a solar-power satellite transmitter. On 12 October, after most of his kin had departed, B6 flew south. He reached Tasmania 11 days later, after a record-breaking 13,560km continuous flight.

DAN RUTHRAUFF/USGS

The last leg of this 29,000-km migration was 11,680km. At the time, this was the longest known continuous flight of any bird – and although it didn't surprise godwit researchers, it did catapult E7 to global fame.

"In 2012, we went to China to do an exchange," explains Lee Tibbitts, a long-time wildlife biologist at the USGS's Alaska Science Centre and frequent colleague of Gill's, including for the tracking of E7. "And folks there knew about E7; there were posters all around town about her."

Tracking these birds isn't easy research to conduct. Indeed, one of the most remarkable discoveries of recent times was the result of hours of arduous field work and a good dose of "sheer dumb luck", according to Daniel Ruthrauff, also at the Alaska Science Centre.

In July 2022, he and Jesse Conklin from the University of Groningen's Conservation Ecology Group travelled to Nome, a small town on the Seward Peninsula in western Alaska. Neither of the experienced wildlife biologists expected to succeed in their unprecedented mission: to find bar-tailed godwit chicks – which leave their mossy nests and begin roaming only days after hatching – and fit them with satellite transmitters to try to learn more about juvenile movements.

After several fruitless days hiking through the tundra, being feasted on by mosquitoes, these "two 54-year-olds with creaky knees" – in Ruthrauff's words – found three tiny balls of fluffy feathers in the shrub. While the chicks' parents flew around screeching and swooping them, Ruthrauff and Conklin caught and glued onto each one a radio transmitter weighing half a gram and measuring 15 millimetres in length, minus the antenna.

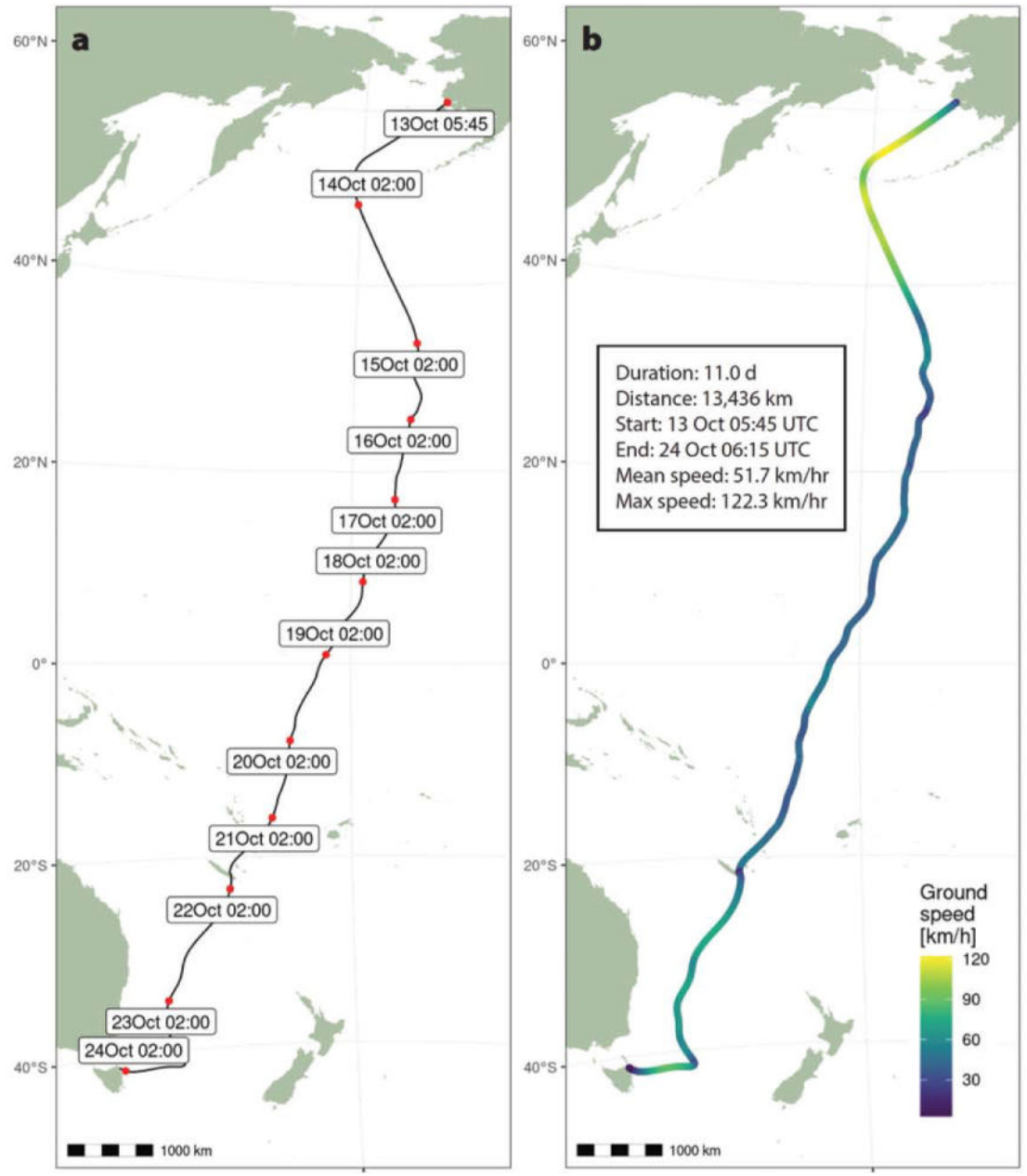
But even with the radio signal, the biologists struggled to follow the brood over the next couple of days. "We thought families would stay within a few hundred metres – maybe a kilometre – within this period. But we were hiking up to a kilometre in just one day," Conklin says.

On 15 July, Ruthrauff and Conklin managed to relocate and recapture the rapidly growing chicks. While the parents mobbed them once more, they replaced the radio transmitters with slightly larger solar-powered satellite ones in loose-fitting harnesses to allow for growth. Then they went home, hoping that the trio of chicks – and the transmitters – would survive.

Not long afterwards, the signal from two of the chicks stopped moving – a sign that they'd died, or that the transmitters had fallen off or stopped working. All attention was on the remaining bird.

This roughly three-month-old male – dubbed B6 – didn't seem like a migration candidate. For one thing, after leaving the tundra, B6 travelled to a site around 100km north of the regular staging ground for bar-tailed godwits on the

Godwit's route



Yukon–Kuskokwim Delta. For another, he was still in this place in mid-October, long after the majority of his kin had left the soon-to-be-frozen Arctic.

But finally, on 12 October, just five months after he'd hatched, B6 took off, heading out over the Aleutian Islands and beyond for the first time.

Eleven days after his departure, he touched down near Ansons Bay, a small holiday village on Tasmania's north-east coast. Over the roughly 250 hours B6 had been continuously flapping his wings in the air, he'd covered a total distance of 13,560km – close to the maximum range of an Airbus A380. And, given most adult bar-tailed godwits migrate separately to juveniles, it's likely that he completed his maiden migration without the guidance or supervision of his parents or any other elders.

Although Ruthrauff celebrated B6's accomplishment, which made news headlines around the world, he couldn't help but laugh about how it was framed. "If calling it a new world record makes people pay attention, that's cool – but these birds are just going about their business. They don't care about records."

JESSE CONKLIN

24 January 2023

The boat glides across glassy water that reflects the blue sky and wisps of cirrus cloud. Robert Dixon drives while Elisabeth Dark – a Birdlife Southern NSW committee member, and the only other person on today's survey – and I hold onto our hats. The air is muggy, the summer Sun hot and bright even though it rose less than two hours ago. Botany Bay is crowded with fisherman and recreational boaters enjoying the last of their holidays.

Dixon cuts the motor when we arrive at Towra Spit Island. Roughly the same number of bar-tailed godwits are roosting on the sand as during my visit a month ago, with a few eastern curlews and masked lapwings mixed in amongst them. But there are no little terns today. "They're usually here and quite active now, darting in and out," Dixon says.

Some of the godwits are restless, stretching wings and calling softly – a high-pitched, sharp *kwee-kee-kwee-kee* – as small waves wash over the island. Many scuttle away from the encroaching tide but others don't pay it much heed, letting the water ripple halfway up their long legs. They haven't yet changed into their deep orange breeding plumage, and although most are plumper than last month, they still need to build up their fat reserves before they're able to fly without stopping to the Yellow Sea.

"Shorebirds are an acquired taste," Dark says, as Dixon navigates back to the jetty. "They might not look very interesting, but once you know their story you can't help but feel inspired by them, feel empathy for them."

It's easy to overlook bar-tailed godwits and other avian wanderers, because their presence in one location is fleeting. And because they aren't dependent on just one place, it can be easy to think that they'll always have somewhere else to go. But their continued existence is fragile, reliant on a handful of irreplaceable locations. Remove or disturb a single link in the chain of a species' migratory pathway, and the consequences can be catastrophic.

For decades, migratory shorebird numbers have been rapidly declining globally. This has been particularly acute among the 50 million birds that, like the bar-tailed godwit, traverse the East Asian-Australasian Flyway (EAAF), which covers an area of 85 million sq. km, from the Russian Far East and Alaska, through East and South-east Asia, to Australia and New Zealand. It's the most threatened of the nine major flyways – essentially huge migratory bird highways – that crisscross the globe.

"Remove or disturb a single link in the chain of a species' migratory pathway, and the consequences can be catastrophic."

Habitat loss through rapid industrialisation is one of the main challenges confronting migratory shorebirds. In 2012 (opposite), bar-tailed godwits staging en route back to Arctic nesting grounds roosted on an active dredge-dumping site near Donggang, in Liaoning Province, China. Rich mudflats such as these on the Yellow Sea shoreline are critical to many species' migration success, but in recent decades they've shrunk by millions of hectares. This dredging project was designed to improve access to a fishing port; the infilled area – excised from the Yalu Jiang National Nature Reserve – was re-purposed as industrial land.

DAVID S. MELVILLE

A 2016 study used 20 years of continent-wide citizen science data to assess population trends of 10 shorebird taxa that use the EAAF. It found that numbers of two bar-tailed godwit subspecies – *baueri* and *menzbieri* – and five other taxa had declined at rates of up to 8% per year.

The primary driver of this steep decline is habitat loss and degradation, especially at the flyway's beating heart: the rich mudflats of the Yellow Sea. For at least 240 bird species, these serve as a one-of-a-kind service station where they can refuel before continuing their migration. But over the last few decades, millions of hectares have been replaced with urban and agricultural land reclamations as population and industry have grown.

One 2014 study found that over a 4,000km strip of coastline between China and South Korea, 28% of tidal flats that existed in the 1980s had disappeared by the late 2000s, and up to two-thirds had been lost over the past five decades.

When Theunis Piersma first visited the area a decade ago, the Yellow Sea situation was so severe that his first thought was that he and his colleagues would soon be describing the extinction of a great number of shorebird species.

Thankfully, this future appears to have been avoided – for now. In January 2018, for example, the Chinese government announced a moratorium on all "commercial-related" coastal wetland reclamation along its coastline, and the following year, a large portion of China's Yellow Sea coastal wetlands secured an even stronger layer of protection in the form of World Heritage status.

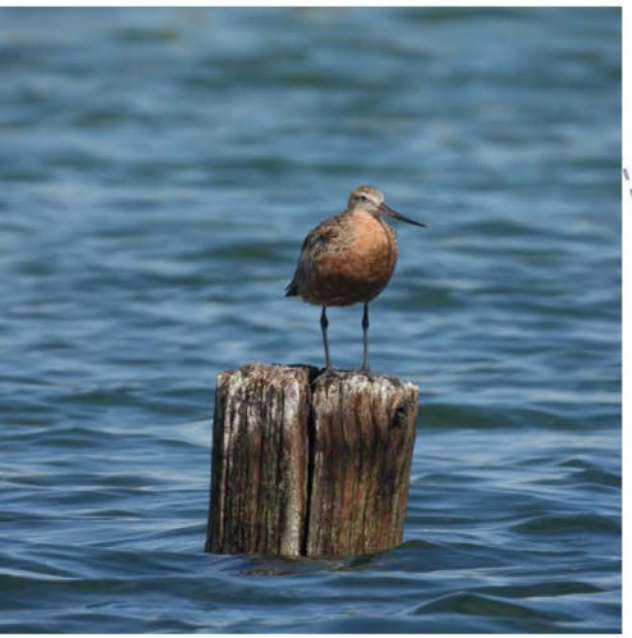
Other countries in the region are now following suit, substituting development policies with ones of protection. This change is driven by the tireless international advocacy of the very same group of people who revealed so many of the bar-tailed godwits' secrets. That advocacy has taken them to some surprising places.

In 2009, for example, Adrian Riegen was part of a small team that travelled to North Korea to set up a migratory shorebird monitoring project. He's been back several times since, each time building up more trust and rapport with the authorities. "We hope to survey the entire coast of North Korea on the Yellow Sea," he says. "I often say under my breath, 'The things we do for shorebirds.'"

But the future for bar-tailed godwits and other migratory shorebirds remains precarious. Throughout their entire migratory pathway, many places they depend on and are deeply attached to continue to be destroyed by development – and even those that are protected are now at risk from one of the major impacts of climate change.

"In the case of the Yellow Sea, you have mudflats that go right up to dykes and garages and things like that," Robert Gill explains. "There's not the luxury of habitat being created further inland if sea level rises. And it's the same problem on the Yukon delta and elsewhere."

It's a fundamental contradiction: as Riegen says, "One of the most important things to remember is how vulnerable they are – despite how robust they are."



DEB ANDREWS X2

The implication of this is as profound as the birds' migration is astonishing: they are able to detect and respond to wind and weather conditions in distant atmospheric regions.

Migration: innate instinct, or something more? Since unearthing that bar-tailed godwits restructure their entire bodies for their migration, researchers have discovered some of the birds' other remarkable talents. Recent satellite tracking has shown that some birds select favourable winds to depart all of the sites along their migratory route, and the days they select ensure the greatest possible overall wind assistance throughout the entirety of their flights. The implication of this is as profound as the birds' migration is astonishing: that they are able to detect and respond to wind and weather conditions in distant atmospheric regions. They're "pretty decent meteorologists", says Gill.

But so many mysteries remain about their epic migration.

How, for example, are they able to perceive distant weather conditions? Why do they develop such strong site fidelity, returning not just to the same general area but to the very same bay, beach or portion of tundra, year after year to feed and breed? Why do adults and juveniles migrate in two separate waves?

How are they able to orientate themselves so accurately that when, for instance, they fly from the Yellow Sea to Alaska, they will track well south of the direct route for about 4,500 kilometres to benefit from favourable winds, before abruptly turning north-east towards their destination while over the middle of the ocean? How can godwits navigate so precisely that, as Piersma says, "it's like they have a GPS on board"? Do they use the stars and Sun, in conjunction with wave

patterns and the Earth's magnetic field, or do they possess tools beyond our comprehension?

"[D]espite decades of research, we remain unable to satisfactorily explain these feats of endurance," Piersma and his colleagues write in a 2022 literature review of shorebird migration.

This statement implicitly rejects an explanation for bird migration that has satisfied some scientists in the past – but is, according to Piersma, "plain stupid". The idea is a product of a kind of scientific thinking that "ignores all of this consciousness around us" and considers *Homo sapiens* to be in possession of uniquely complex ways of being, behaving and thinking.

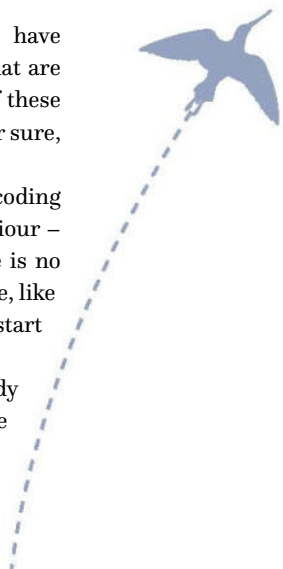
"Migratory birds, like most animals, have historically been looked at like machines that are all just genetically programmed to do all of these fantastic things," Piersma says. "But that, for sure, is a big mistake."

While he accepts that genes, by their encoding of proteins, probably influence avian behaviour – much as they do human behaviour – there is no doubt in his mind that bar-tailed godwits are, like us, "learning entities. And we're only at the start of understanding what that really means."

Jesse Conklin echoes this sentiment. Study and observation over many decades has made him realise that these birds are not "like robots" controlled by an identical genetic blueprint. They are "sentient creatures" that possess individual personalities, learn from trial-and-error, and are capable not only of extreme feats of flying but also extreme feats of communication, memory and intelligence.

"I don't know whether this all gets me closer to understanding bird migration," Conklin says. "But it's certainly fascinating. We just find more and more possibilities the more we look. We're not finding the unified theory of migration" – because, he adds after a brief pause, "that doesn't really exist".

Like us, bar-tailed godwits are "learning entities", according to the University of Groningen's Piersma. Those in a reserve near Sydney's Port Botany (above), for example, have adapted to the container terminal's bright lights – they now also feed at night.



21 February 2023

It's a scorching, windless morning and Dixon is back out on the boat in Botany Bay – this time with the help of Deb Andrews, a retired National Parks and Wildlife Service natural heritage officer, and Dr Michael Fleming, a research ecologist.

We find a flock of 24 bar-tailed godwits roosting on a small beach near the Taren Point Shorebird reserve, and a solo male perched on a post in the middle of the water. The feathers on his breast are a deep cinnamon colour and he is so fat that he looks like a mini soccer ball about to pop.

As we approach Towra Spit Island, a large flock of birds takes flight, heading north-east. They rapidly gain height, spreading out and coming together as if they are a single, breathing organism. Silhouetted against the sky, the trace of their flight resembles calligraphy on pastel blue paper. They wheel around to the west; in a couple of seconds they're directly above the boat. It's then we see that they are bar-tailed godwits.

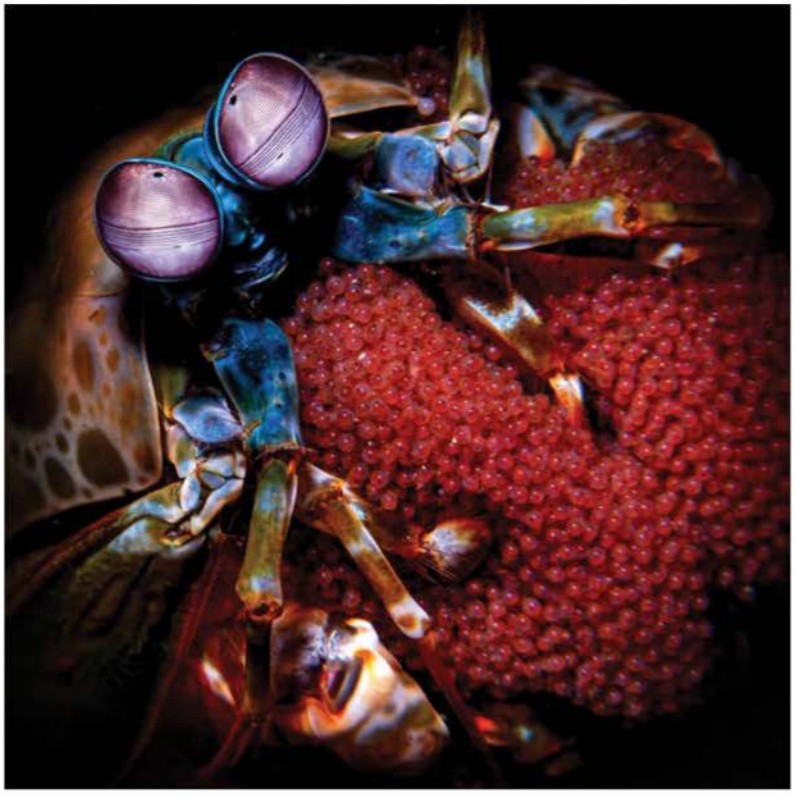
For a moment, the 50 or so birds are so close that we can hear the sound of their sharp, powerful wings above their calls to each other. Then they wheel back towards the island in a tight formation and land on the sand. But not a second later they take off again – and for the next 30 minutes, we watch as they perform this same dance four more times, perhaps a sign of a disturbance or predator we cannot detect, or perhaps a sign of their *Zugunruhe*. When the flock finally re-joins the bar-tailed godwits on the island, we're able to get a better look at them through our binoculars and count roughly 200 birds in total. All are plump with fat for their upcoming flight to the Yellow Sea, and the males are in near-full breeding plumage.

"I don't think it's long now until they fly back north to breed," Andrews says. "They're already dressed for the party."

DREW ROOKE is based in Sydney. This is his first story for *Cosmos*, and a part of our 'New Ways of Seeing' series enabled by a grant from the CAL Cultural Fund.

This one planet

Vibrant and mesmerising, candid and electrifying, the entries to the 2023 Sony World Photography Awards tell a thousand different stories of our Earth.



My precious

The reef-dwelling harlequin mantis shrimp (*Odontodactylus scyllarus)* went viral a few years ago when researchers discovered that it has the fastest punch of any living animal – 80km/h, used to smash through its prey's exoskeleton. This individual is focused on protecting its clutch of eggs. The photographer says it took several minutes to "obtain this visual contact with both eyes, considering they can be moved independently in all directions".
Shortlist, Open Competition, Natural World & Wildlife

Photographer: Andrea Michelutti, Italy

Winter is coming

If you could watch the Patagonian landscape change over deep time, you would see glaciers flow, swell and retreat; volcanoes spew out lava that would become plateaus; rivers carve out deep, wide valleys; continents smash together and rip apart. But on human timescales, changes are visible with the seasons, including spectacular autumn shows as deciduous trees prepare for winter.

Shortlist, Open Competition, Landscape

Photographer: Bing Le, Canada

The pace of reflection

Some shots don't need fancy equipment, just the right timing. "I was on a train passing through Andhra Pradesh state in India, when I saw this scene," says photographer Indirani Thevar. "I photographed it with my mobile phone." Andhra Pradesh is also known as the 'rice bowl of India'; the region flooded several times last year, hit with heavy rains that caused major rivers to swell.

Shortlist, Open Competition, Landscape

Photographer: Indirani Thevar, India

Catch me if you can

Spotted here among fan corals near Tulamben, Bali, this pygmy seahorse (*Hippocampus bargibanti*) is covered in reddish bumps known as tubercles. The species blends in so perfectly with its surroundings that it wasn't discovered until specimens of its host coral were examined in a laboratory in 1969, and the researcher happened to notice two tiny seahorses among the bright colour.

Shortlist, Open Competition, Natural World & Wildlife

Photographer: Charly Clérisse, France

Game on

This twisting, leaping behaviour of the stoat (*Mustela erminea*) still puzzles researchers. Is it an involuntary response to parasite infections, or is it part of the hunting process? "Sometimes, the dances are performed in front of a rabbit or large bird in an apparent attempt to confuse or distract potential prey," says photographer Jose Manuel Grandio. "But on other occasions – as here – there is no prey animal in sight." Perhaps it's practicing.

Shortlist, Open Competition, Natural World & Wildlife

Photographer: Jose Manuel Grandio, Spain

Dawn portal

Through the haze of morning, three deer emerge from the orange mist to cross defunct railway lines in Hungary. More than 100,000 red deer roam the country's woodlands; the stags in particular are highly prized by hunters.

Shortlist, Open Competition, Natural World & Wildlife

Photographer: Tibor Prisznyák, Hungary

Running the gauntlet

Each year, more than a million wildebeest trek from the Serengeti Plain in Tanzania to the lush grasslands of the Masai Mara in Kenya, seeking fresh grazing and water. Their greatest obstacle is the Mara River. Crossing it is no easy feat when crocodiles lay in wait in the water, and this image captures the panic and frenzy of the wildebeests – but also their explosive power and athleticism.

Shortlist, Open Competition, Natural World & Wildlife

Photographer: Arnfinn Johansen, Norway

The dune soundtrack

With their chiselled ripples and pockets of shadows, the sand dunes of Death Valley in California form a beguiling landscape. The peaks can rise to over 200 metres tall, and if you stand at the very top, the sand may sing to you. As sand grains slide down the dunes' steep faces, the friction produces a sound akin to the bass note of a pipe organ, humming through the desert.

Shortlist, Open Competition, Landscape

Photographer: Marcin Zajac, Poland

Earth pyramids

Gothic spires, landslide towers, alien geology – these spectacular formations have been called many things, but their true origin lies in ice. Rising out of a forest in South Tyrol, Italy, these geological pillars were once part of a loose, rocky deposit left over by a glacier. Over the years, surface water has eroded away much of the deposit, but large rocks act as a protective cap, leaving some columns still standing – for now.

Shortlist, Open Competition, Landscape

Photographer: Robert Bilos, Croatia

Hot feet

This chinstrap penguin appears to be out for a delightful jaunt on the Antarctic ice, but the solitary figure it cuts is painfully prescient. Like all polar species – including its favourite food, krill – this penguin (*Pygoscelis antarcticus*) lives under the darkening shadow of our fossil fuel addiction; in some colonies, population numbers have more than halved over the past 50 years.

Shortlist, Open Competition, Natural World & Wildlife

Photographer: Alex Pansier, Netherlands

What's below the ice?

Near the opposite pole, on Norway's Svalbard archipelago, a lone polar bear navigates the rocky landscape of the Nordenskjøld Land National Park. "A decade ago there was a glacier," photographer Mark Fitzsimmons says. Svalbard was originally settled for mining purposes; Norway is closing the last coal mine by 2025, but continues to open up new oil drilling areas in the Arctic.

Shortlist, Open Competition, Natural World & Wildlife

Photographer: Mark Fitzsimmons, Australia

Sci-fi to science: intensely detailed imaging coupled with AI has succeeded in listening into minds and transcribing what it finds there. By **Richard A. Lovett**.

Brain eavesdropping

Mind reading is a staple of science fiction. In the original *Star Trek*, for example, Spock would occasionally perform the Vulcan mind meld, in which he splayed his fingers across another person's face while intoning: "My mind to your mind; my thoughts to your thoughts." It was fun stuff, but not something most scientists of the time took seriously.

But they were wrong. It is becoming increasingly possible to read what is happening in people's brains, though not with mysterious Vulcan telepathy. It uses computers and an imaging technique called functional magnetic resonance imaging (fMRI), and it's leapt straight from science fiction to front-page news. At the moment, its uses are limited, but how long will that last? Will we soon be truly able to read people's minds?

Next-gen imaging

Conventional MRI of the type used in medical exams is tuned to detect the hydrogen atoms in water, from which it can create 3D images of everything from sports injuries to tumours. fMRI uses the same scanner, but focuses solely on the brain, and is tuned to detect oxygen. This allows it to determine the rate of oxygen usage in your brain, on a millimetre-by-millimetre scale. Areas that use a lot of oxygen are busily working. Low-oxygen-use areas are idle. Want to know how coffee alters your morning brain? Use fMRI. Want to know if pornography affects parts of the brain related to impulse control? fMRI might provide a clue. "It's like measuring which parts of a city are active by where the lights are turned on," says Alexander Huth, a neuroscientist at the University of Texas, Austin.

That type of research is critical for understanding how the brain functions, both normally and under adverse conditions, but there's another use, which researchers call "decoding" the brain. It uses fMRI to attempt to figure out what your brain is doing during the scan – as in, it's trying to read your brain.

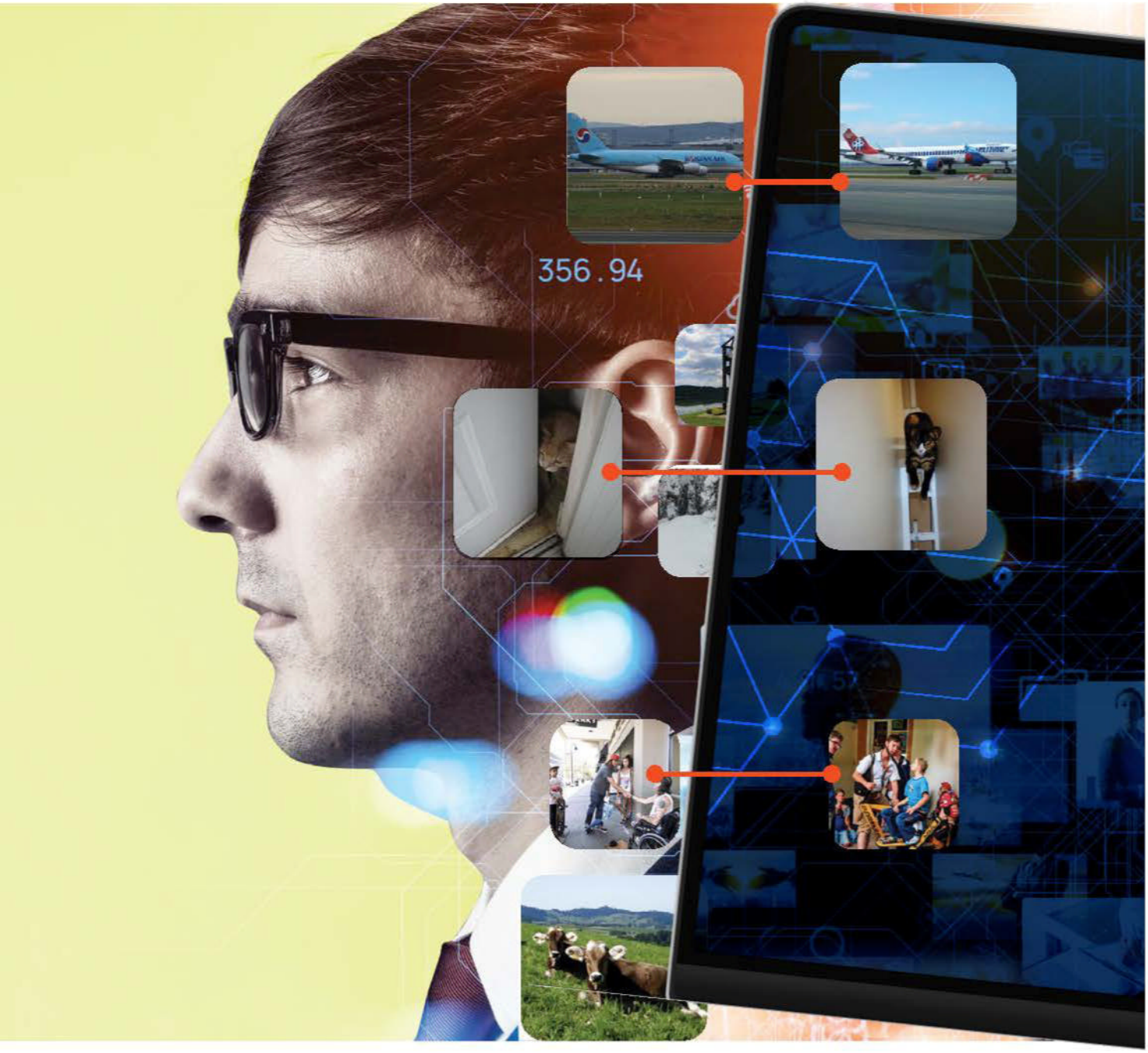
The earliest work focused on the visual cortex, which occupies a large fraction of the brain's outermost layer, making it easy to acquire detailed scans. Not that it's wired like a megapixel camera, with each tiny segment recording the colour and intensity of light falling on a specific part of the retina. It's vastly more complex, because the visual cortex isn't just recording what comes from the eyes, it's processing it.

But with a powerful enough computer, it's possible to show people a series of pictures and create computer models of how their brains encode those images. And once you figure out how the brain encodes information, the next step is obvious, says Jack Gallant, a neuroscientist at the University of California, Berkeley (UC Berkeley): "You can decode."

As far back as 2006, it was possible to show people photos and reconstruct at least an approximation as to what they were seeing. Those early results were mostly a demonstration of concept, though in 2014 researchers at Yale University showed photos of faces to their test subjects and were able to decode images that, while not great, were in some cases quite recognisable.

When MRI met AI

Since then, brain-scanning techniques haven't changed all that wildly, but computers have. "The



(FACE) METAMORWORKS/GETTY IMAGES

AI has helped immensely in the quest to reconstruct an image from a test subject's brain activity. But the details are still hazy: is that plane a Boeing 737, or an Airbus A320? Is that cat behind a door, or on a ladder? For that matter, is it even a cat at all?

state of the art in terms of reconstructing images from brain activity has gotten incredibly good," says Brice Kuhl, one of the members of the Yale team, now at the University of Oregon. As examples, he references two as-yet unpublished papers, currently available on arXiv, one by a team in France and the other by a team in China. These papers use advanced AI programs to sharpen the details of decoded images, producing results that look a lot more like photographs. A passenger jet on a runway, for example, is clearly a passenger jet on a runway, not a vague shape that might be a jet … or a cigar with wings.

Not that it's perfect, or anywhere close to it. The reconstructed image of the plane doesn't match the one in the original photo – maybe because the people whose brains were being scanned neither knew nor cared about the difference between, say, a Boeing 737 and an Airbus A320. And there are cases where even the latest AI programs get it laughably wrong. When people were shown an image of a cat peering through a crack in a door, the decoder produced everything from a cat descending a ladder to a dog leaping out of a wall. Bottom line: this image was so far outside of the AI's training set that it filled in remarkably sharp details … of nonsense.

Meanwhile, Huth has been trying to crack a more difficult nut: how the brain decodes speech. "This is a problem I've been working on for 15 years, [since] I started grad school," he says. And in a paper published this May in *Nature Neuroscience*, his team finally succeeded. "We were shocked that it

works as well as it does," he said at a 27 April press conference.

Like the research into decoding vision, the process begins by putting people in an fMRI scanner and recording their brain activity as they listen to stories. It isn't a quick process, like setting up your mobile phone for face or fingerprint recognition; it took many sessions, totalling 16 hours per experimental subject. To avoid boring participants out of their skulls, Huth's team kept it entertaining with TED Talks and podcasts from an American radio storytelling show called *The Moth Radio Hour*. "[That's] critical for getting good fMRI data," he says.

They had their test subjects listen to stories they'd not heard before, and attempted to reconstruct them from how their brains reacted.

Using this, his team built models of how each person's brain responded to a wide range of word sequences. Then, they had their test subjects listen to stories they'd not heard before, and attempted to reconstruct them from how their brains reacted.

The results were impressive but intriguingly non-literal. For instance, says Jerry Tang, a graduate student who did much of the work, when one research subject heard a story in which the narrator said, "I don't have my driver's license yet", it came out as: "She is not ready; she has not even started to learn to drive yet."

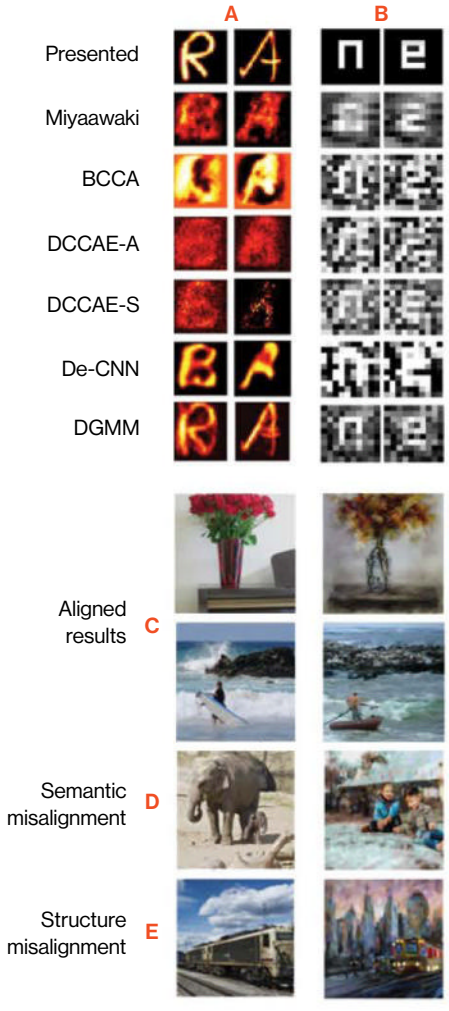
Huth thinks this means the scanner isn't just recording how we translate sounds into words, but is finding a higher level involving how we interpret them. In part, that may be due to a quirk of fMRI: the changes in blood flow it measures take 3–4 seconds to peak, then another 5–6 to fade. That means it can't show the brain's response to individual words, but is instead measuring what Huth calls an "agglomeration of information over a few seconds". The overall idea comes through, he says, "even though the exact words get lost".

Supporting this is the fact that when his team showed their subjects short animated films, such as an emotionally powerful Dutch fantasy called *Sintel* or short subjects from Pixar Studios, the brain scanner recorded a decent approximation of the story line, even though these films either had no dialogue, or the dialogue had been removed. "I think we are decoding something that is deeper than language and converting that into language," Huth says.

Not that there aren't glitches. One of the test stories included a depiction of a lovers' spat in which the storyteller said: "I didn't know whether to scream, cry, or run away. Instead, I said, 'Leave me alone; I don't need your help.' Adam disappeared, and I cleaned up alone, crying." That was reconstructed as: "[I] started to scream and cry, and then she just said, 'I told you to leave me alone, you can't hurt me anymore. I'm sorry.' And then he stormed off. I thought he had left [and] I started to cry."

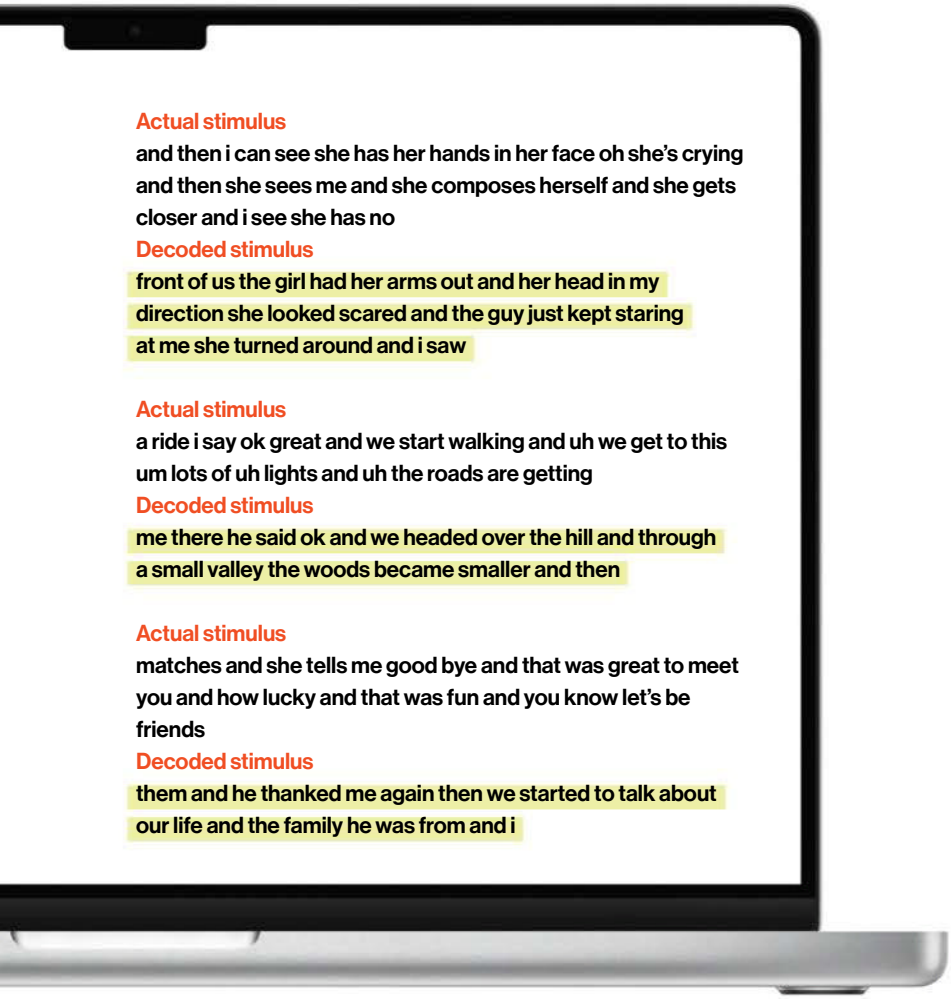
Such sidetracks happen, Huth believes, because

Spot the difference



The galloping sophistication of brain decoders is apparent in the sequences (above), drawn from research published by a Chinese Academy of Sciences team. Their 2018 work proposed a novel deep generative multi-view model (DGMM; top, line 7) for accurate visual image reconstruction of human brain activities measured by fMRI (top, line 1). Later image-based iterations (4 lower lines) from a current pre-press article aren't perfect – but the improvement is manifest.

LEFT, FROM TOP: RESEARCHGATE.ARXIV.



the decoding process uses statistical techniques that guess the progress of word sequences as they are proceeding, then check their guesses as the sequence continues. If they misguess, they can go off on a tangent, but they have a tendency to self-correct.

"It can be a bit hazy at first, but find its way back," Huth says.

Another problem, Huth notes, is that the current algorithm seems "uniquely bad" at pronouns.

Published in early May, Alexander Huth and team showed (above) that it's possible to use fMRI brain recordings for semantic reconstruction of continuous language. "We were shocked it worked as well as it does," said Huth.

DREAMS AND NIGHTMARES

Brain decoding, especially for speech, holds the promise to make many people's lives better, especially those with major disabilities. "[W]e hope that this technology can help people who have lost the ability to speak due to injuries like strokes or diseases like ALS," says Jerry Tang of the University of Texas.

Brain decoding also offers the prospect of recording and examining dreams and of building highly functional brain/computer interfaces. It is also a major step in understanding how the brain works.

But there are other potential uses, including brain hacks probing for financial data, passwords, business secrets or anything else that could be stolen from our minds. It could be used as a lie detector (complete with all the same concerns about accuracy as with today's polygraph tests), or be used by police and prosecutors to search our brains and turn our deepest thoughts against us.

"It doesn't know who is doing what to whom," he says. "It doesn't know if it's in the first person or the third person, or whether to use male pronouns or female pronouns. Why, we don't know; it could be that that kind of information is just not very well captured by our model, [or] it could be that [it] is represented in some way in the brain that is hard to get at."

The sinister subtext

As of now, it's not possible to use fMRI to read our secret thoughts, in part because fMRI requires large, expensive and not easily portable equipment. Other methods of capturing brain activity do exist, such as electroencephalography (EEG) and magnetoencephalography, which measure the electrical activity of the brain, and functional near-infrared spectroscopy (fNIRS), which uses minute changes in heat emissions as an alternative way to measure changes in blood flow. None work at the millimetre resolution produced by fMRI, but any might evolve into a simple brain-scanning headset for which privacy might be an issue.

All the way back in 2012, Dawn Song, then a graduate student at UC Berkeley, got to worrying about this in the context of gaming-style brain/computer interfaces. As a test, she created a game whose set-up routine included images of a bank. She then put numbers into the set-up process, looking to see how the user's brain reacted to them. And lo and behold, using this relatively crude process (which didn't even use fMRI, but instead used EEG), she could tease out her volunteers' debit card PINs. Bottom line: brain hacking is a very real threat.

One way to protect yourself is simply to refuse to cooperate. Nobody can steal your PIN via a computer game if your refuse to play the game. And even if you were forced to take an fMRI scan, you could defeat it, Tang says, either by refusing to hold still or by performing some sort of mental gymnastics, such as doing math problems or telling yourself your own story – tricks, he says, that confuse the scan enough to make it useless, at least with present technology.

That said, the technology is evolving rapidly, which means it might soon be possible to decode someone's thoughts against their wishes. "So, while this technology is [still] in its infancy," Tang says, "it's very important to regulate what [it] can and cannot be used for. Then, if one day it does become possible to get accurate decoding without a person's cooperation, we'll have a regulatory foundation in place."

RICHARD A. LOVETT has written regularly for *Cosmos* for many years. His most recent story for the magazine, about returning rock samples from Mars, appeared in

Lady Elliot Island, now reafforested after several denuding decades of guano mining from the 1860s.

TOURISM AND EVENTS QUEENSLAND

ONE PLACE MANY FUTURES

It's a dot in the ocean you could cross in 10 minutes, but in the waters surrounding the Great Barrier Reef's Lady Elliot Island, scientists are finding new species, and documenting an ecological treasure box that may hold the key to our marine future. **Ashley Hay** reports.

The colours are blues, only blues: clear sky and bands of differently deep ocean. The smells are sea-salt and the warm-woody-spicy-sweet of clove oil. The sounds are the complementary noises of a vessel moving in water and water moving against a vessel.

A row of clear plastic bags, each secured at the top, sits on the bench seat that runs along the side of this glass-bottomed boat. Each bag holds a few small fish – looking just like they have been purchased and packaged in a pet store. Small oval blue-black creatures with flecked white tails. Thin black and white striped creatures, the size and shape of a finger. These are reef fish, part of the marinescape I can see through the boat's clear floor. Reef fish, like clown fish and surgeon fish: Nemo and Dory. But these ones don't have a name yet – not cartoon names; species names.

The three scientists who've just hauled themselves – and these fish – out of the water are Mark Erdmann, Asia Armstrong, Christine Dudgeon. They drip and talk as they divest their diving gear: masks, tanks, snorkels, weights. These fish, they suspect, are new species. Unknown, unnamed, unclassified – to date. "We have things here we didn't have yesterday," Erdmann remarks.

One bag, these small things – new things – swimming inside its clear caul. Tiny creatures from the hold of this water that ebbs and flows in the Great Barrier Reef: one of the most studied, most discussed and debated, most visited and imagined places on the face of the Earth.

Old fish, new fish

This is a story about some very small fish that haven't been studied before. In that way, it's a story about biodiversity and knowledge. A story about what science looks like in the particular place of this survey on this tiny island, at this particular time, the third decade of the third millennium.

It's a story about the people who do this work, and why it matters. It's about accretion in the natural world, and in the world of knowledge and imagination too. It's curiosity and discovery; hope and optimism; and wonder. That's an important one. Maybe these aren't the words you'd expect about something rooted in science, but more and more, they feel like the best and biggest kinds of words to deploy.

The Great Barrier Reef (GBR) is, famously, a best and biggest thing – not just the planet's largest living organism, but also the only structure on Earth built by a living community and visible from the Moon with the naked eye. At the southern end of its 3000km-span sits the fullstop of a coral cay – Lady Elliot Island (LEI). Just 45 hectares in size, the island can be circumnavigated on foot in less than an hour. One dotpoint: 24.1129° S, 152.7140° E. A precise and literal drop in this ocean.

It's a particular and useful place to study. For one thing, islands matter: they're often discrete ecosystems demonstrating evolution in action, offering examples of colonisation, adaptation or maybe even speciation. They're model systems, in a way.

Now, too, there's a different potential in understanding what's happening in various 'souths' in the southern hemisphere, and a different freight and potential in understanding what's happening in island systems. As elements warm – air or ocean – many organisms will increasingly attempt to move to cooler latitudes. LEI is the last point that an organism seeking a southern migration along the Great Barrier Reef can successfully achieve. Beyond it, there's a hundred or so kilometres of open water south to Kgarri/Fraser Island.

If this island sits at the end of a potential travellator of future refuge for relocating species, not only is it important to understand what's already here before they get here – and how their arrival might impact that – but also how they might be helped to head back north again, in that future-time we have to hope is coming.

The Great Barrier Reef is the only structure on Earth built by a living community, and visible from the Moon

Chris Dudgeon (below, at left) and Kathy Townsend, right, survey the shallow waters around LEI. Opposite: More than 1200 marine species make their home on LEI on a reef that's so noisy, hydrophones can hear it from more than a kilometre away.

All of which is part of why Erdmann, Armstrong and Dudgeon are on this boat on this lapis-lazuli-bright morning. They're members of Leaf to Reef, an arm of the Reef Islands Initiative and a collaborative research project that's been running since early 2020, overseen by Kathy Townsend from the University of the Sunshine Coast (USC).

As a starting point, the project wants to know what lives in this particular dot from the long catalogues of things known in this part of the world – corals, fish, marine mammals, plants, birds and other vertebrates. The thing is, it's also finding things those catalogues don't record yet. And not only fish expanding their range to places they haven't been found before – they are finding that, and that's exciting. But they're also finding fish species altogether new to science – and possibly as many as 11 (see page 90). In an era where stories of biodiversity tend to err towards the extinction end of the scale, with Australia a dubious leader in this decline, there's something wonderful in witnessing work that reveals the other end of the spectrum.

Erdmann puts it like this: "As a fish taxonomist I look at the GBR as a place that has been studied upside down, inside out, one way and the other – it's probably the most studied reef system in the world. The idea that there are still new things to be found here – it highlights that the ocean is an amazing place."

Ocean optimists

Kathy Townsend always had the ocean in her sights. She was the six year old with a field guide who knew what a sea urchin was even though she lived in the land-locked Canadian city of Calgary. "I was a prairie girl," she says: "Mountains on one side and a river on the other. I like to know my limits – that's why I like living on islands. There's something about knowing where the edges are."

Five years ago, she established Leaf to Reef, a core of 11 researchers with a growing suite of collaborators and contributors – including a phalanx of citizen scientists – that push the project's

LEFT: MARK ERDMANN. RIGHT: TOURISM AND EVENTS QUEENSLAND.

resources in as many directions as they can to understand biodiversity and connectivity. In terms of southern migrations, and the idea of organisms returning north again, Townsend calls herself an optimist: "I think they will be able to go home." She began to imagine Leaf to Reef after reading two *Science* papers. While both explored rates of terrestrial and marine connectivity and recovery on smaller island study sites, the healthiest landscapes had manta rays. Designing Leaf to Reef presented an opportunity to build on years of manta work on LEI to think about arks, recovery and connectivity, across a bigger landscape: the GBR.

Another key member of the project is Chris Dudgeon. A marine biologist based between USC and the University of Queensland, her primary research focus is sharks. She's the team's Macgyver, her hand up when there's something new to learn, do, make or invent. "That doesn't just require a particular skillset," Townsend acknowledges. "It needs the personality to say, always, 'yes, I can do that; yes'."

Dudgeon is the sort of person who borrows a tap and die set (which create threaded pairs of screws and holes) to whip up a new tagging applicator – for sharks, for mantas – ahead of a field trip. Innovation on the go; a long way from her regular habitat of quiet labs and white lab coats.

And then there's Asia Armstrong, also from USC, whose oversight of the separate Project Manta database gives her the impressive distinction of being the person best placed to identify individual manta rays along Australia's east coast. Armstrong keeps a weather eye on manta movement as part of Leaf to Reef, adding to understandings of the rays' habits and habitats.

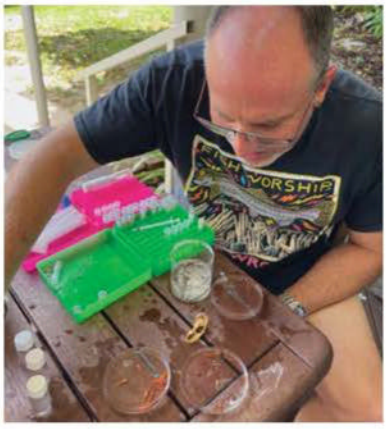
But the main focus of these marine explorations is much smaller. By the time Mark Erdmann, vice president of Conservation International's Asia-Pacific Marine Programs, arrived in 2022, Leaf to Reef had run eight research trips to LEI. As a consultant ichthyologist, he was there to augment the work that Dudgeon, Armstrong and Townsend had underway. "I consider myself an ocean optimist," he says. "There are a lot of threats to the ocean that need us to be concerned about them, but there are definitely bright patches, bright spots."

There's a friendly warmth and energy to Erdmann, and he has great stories. Like the time he accidently found a new species of coelacanth – only the second known to marine science – in a fish market while he was honeymooning. His enthusiasm is matched by a distinct talent for looking into water and seeing, clearly, what's there: not just what's present, but what's new.

> **"There are a lot of threats that need us to be concerned about them, but there are definitely bright patches."**

On his first day on the island, as Dudgeon tells it, Erdmann made it only a few metres into the waters of Lady Elliot's lagoon before he looked

Old school methods; new school fish



The work of identifying a new species is painstaking, and the system is largely unchanged since the field of taxonomy was formed. Fish are euthanised and painted in formalin, then examined for minute differences in form. "You have to count the fin rays and the scales, the teeth, the shape of the teeth ... the different colours and morphologies," says Erdmann (pictured above).

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LADY ELLIOT ISLAND

down, and pulled up, stopped in his tracks by something he'd never seen before. Armstrong teases him about this same laser-focus when he's diving: "Mark gets in and he's swimming, swimming, swimming and then [imagine here the sound of screeching brakes] because he sees a little sandpatch in the middle of live coral." As Erdmann concurs: "I know exactly the sort of things that are going to live there. And sure enough, there's something very interesting."

It's important to quantify the attention required to notice something very interesting. Erdmann shows me one tiny fish, not much more than a centimetre long: "See, this one has a stripe below the eye where usually the stripes stop further back." That's the level of detail at play, moment by moment, fish by fish, under the water at first, and then above.

When Erdmann talks about being inspired by the writings of Charles Darwin and Alfred Russell Wallace when he was a boy – their stories of natural history, of their own travels and collections – he's describing experiences of field research not a million miles from what he's doing now, well over a century and then some down the track.

For each putative new species, for example, a type series must be assembled – and here, it's about following the same protocols Darwin, Wallace and so many other natural historians have followed. Each series comprises 12 specimens from the one locality that range through "little juveniles up to full-size adults", as Erdmann explains, and these series, as well as now being helpfully and digitally photographed, are distributed in complete sets to different museums around the world.

"There are parts of the GBR that are really hurting, and there are other parts that are looking pretty damn good ... the complexity is important," says Erdmann. "But it's a continuous theme with human beings – we like to make things simple. The reality is nature is never simple; it's fucking complex."

Nor is it solely spotting the fish that requires a particular kind of attention; delineating new species of fish needs that too. A damselfish, for instance, requires 14 separate counts of various fin rays, gill rakers, teeth, and vertebrae plus 27 separate measurements – the only difference is the callipers used to make these measurements are electronic now. And through all these enumerations, a type series becomes the gold standard for the compare-and-contrast of any next round of ichthyological work that hopes to determine if another discovery is a fish already classified, or a next new and unknown creature.

To enable this work, the fish – freshly euthanised with a palliative sedation of clove oil (hence the particular and unforgettable fragrance of this story) and removed from their small bag or vial of water – are carefully pinned to display their full extent, every ridge on every fin fanned out, and so on. And then, old-school, they're painted with

Gerry Allen (above, at front) and Mark Erdmann, rear, have dived multiple reefs to understand the ocean's diversity and species range.

MARK ERDMANN

formalin, a saturated solution of formaldehyde that preserves colour and shape. The preservative's recipe is 140 years old, but this step in taxonomic work has not changed since even further back with the institution of the Linnean system in the 18th century.

"There's still a lot on this planet that we don't know," Erdmann says. "I like to say that to children: you know, it's not all done. We don't know everything there is to know about life – especially in the oceans, but anywhere. So then put that in the context of losing biodiversity on a daily or hourly basis ... The Earth has always been changing, of course, but it's changing very rapidly right now.

"If you take the sum total of biodiversity that exists on the planet – fishes, trees, mice, whatever else: that's basically our library of solutions to change. That's our library, all there. If we're busy throwing out a lot of books, we're not doing ourselves any favours."

Library of life

Erdmann's work is only the beginning of the process that will answer the question of whether these potential new species – *Tomiyamichthys*, *Ctenogobiops*, *Priolepis*, *Eviota*, (all four, collectively, the gobies) *Pomacentrus* (the damselfish) and more – are new entries for the library of life. Just as a library needs many authors to write its many books, this work needs a team to pin down new knowledge – each with their own niche of curiosity and expertise.

At the apex of the fish work for Leaf to Reef sits Gerry Allen, the senior author who'll work with a team of ichthyologists around the world to produce these fishes' benchmark descriptions.

"Gerry is the world expert on damsels in particular," says Erdmann, "and a strong expert on the shrimp gobies. The dwarf gobies will go to two other men who are world experts: Dave Greenfield is the dwarf goby guy; Rick Winterbottom is the pygmy goby guy. But Gerry will look at all the material."

Allen arrived in Australia in 1972 to take up a job at the Australian Museum in Sydney, moving across the continent to the Western Australian Museum in 1974. His work has taken him beyond the north of that state and offshore to sites like Christmas Island and further again to the Coral Triangle, which includes the waters off Indonesia, Malaysia, the Philippines, the island of New Guinea, Timor L'este. He has close to 600 new fish descriptions to his name – a powerful number to situate within the library of biodiversity overall. Australia alone is a continent in which taxonomists

estimate there are still some 500,000 species – or 70% of what sits on our library's shelves – that are still waiting to be found and formally named.

It was Allen who brought Erdmann – who'd previously focused on mantis shrimp – into the world of ichthyology when the two met on a post-tsunami survey of Indonesian reefs in 2005.

"I was meant to be looking at how the tsunami was impacting the corals and the mantis shrimps; Gerry was looking at the fish," Erdmann remembers. "Well, he, of course, said, 'bugger that stuff – come and help me with the fishes!' ... After two years of doing that, I'd developed a bit of an expertise myself on the dwarf gobies and some of the smaller reef fishes. We became a somewhat inseparable buddy pair, and we've gone all over the place surveying reef fishes and finding new species."

Allen's citation for an ichthyological lifetime achievement award he received in 2016 noted that he'd logged, at that time, more 10,000 hours in scuba-diving, and 12 solid years of fieldwork across a 50-year career.

So it's interesting how rare this kind of survey work – the pure focus of Allen's career –is these days. He describes it as "definitely underfunded and probably unfashionable," and he wonders if Leaf to Reef might be "a special situation ... in some ways [it's] doing what we were doing 50, a hundred years ago: going to an area that's unknown ichthyologically and putting it on the map."

> "If you take the total of biodiversity that exists on the planet, that's our library of solutions to change."

Any reflection on all those dives, all those discoveries, nudges the usual meaning of "the opportunity of a lifetime" in a beautiful way: this is the work of lifetimes, passed on from one generation to the next. There's even a fish named for him – *Tomiyamichthys alleni*, or Allen's shrimpgoby, noting another biologist's gratitude to Gerry for his help with studying these tiny fish and adding yet another to the taxonomic lexicon.

The many that make one

The British navigator Matthew Flinders – the first person to circumnavigate Australia and the person who gave the GBR its name – wasn't aiming for singularity when he did so. While the designations "great" and "barrier" came from him, both his journal and its accompanying chart referred to "reefs" in the plural. These were the various "Great Barrier Reefs", their north in no way like their south – which now, in part, is what might help this great system in the times of greater change and adaptation. But in many ways, the name became a barrier in itself – as a famous destination, people know this moniker even if they've never been here, or only ever seen it on TV.

Because to refer to "the Great Barrier Reef" – like referring to "the world's biggest living organism" – is to imply that GBR is one thing. Which not only diminishes the complexity and variety of what lives here, it allows the reef to become a kind of shorthand, emblematic of the horrifyingly large category of things at risk from a changing climate.

That compression, that simplification also diminishes the almost overwhelming wonder of the reef's scale and its diversity: there is documented death and damage thanks to bleaching, poor water quality, rising water temperatures and on-shore development in vast parts of this system – but at this southern end of GBR's great long run of corals, Lady Elliot Island's reefs are enjoying that current advantage of that southern-ness.

And the corals, the fishes, the marine biota that live here on LEI? Well, they're simply stunning.

ALL IN A DAY'S WORK

Leaf to Reef's fieldwork days – packed into three blocks of two weeks each year – can stretch for up to 18 hours as the team work to do as many things as they can. They're leery of advertising this, modern OH&S being what it is, but it feels important to specify the effort involved in this kind of undertaking. A day might involve circumnavigating the cay in its shallows to take an image every 2m to ground-truth a section of Chris Roelfsema's satellite map of the entire GBR as well as banding red-tailed tropicbirds (*Phaethon rubricauda*), some of which have been returning to the same nest for more than 23 years. At this time of year – it's February – there are turtle hatcheries to monitor: both green (*Chelonia mydas*) and loggerhead (*Caretta caretta*) turtles nest here. There are samples of sand, coral, algae and plantlife to collect; these are dehydrated for further testing on the mainland ("a ready-made reef," Townsend quips. "Just add water"). Plus they'll survey ocean transects and deliver public talks for the tourists amongst whom they're working. More than once these talks have flushed out a willing volunteer citizen scientist. (One man, a professional bore driller, offered to spend his holiday sampling water from across the island.) Then there's the constant upskilling for new tech, new equipment – like learning to fly drones or passing the complicated protocols required before birds can be banded. And there's the processing, the cataloguing – of fish, of photographs, of information. It's a picture-postcard-environment to work in, but the hours are many and long.

It is a glorious other-world underwater here, so completely separate from just about anything human – the odd buoy, the odd marker notwithstanding. To swim submerged is to lose the feel of wetness; it's a cradling, not a washing or a splashing, when you're held entirely in its space. There's an ethereality in the combination of quietness and the processive, floating movement of kicking out with flippers through a beautiful and extraordinary landscape, and it's this other-ness that makes it so powerful to visit.

Amidst a constant display of colour and life, it is almost impossible to make sense of the fact that how humans live – the choices we make and what we do out there in our own distant big and loud communities – could possibly touch this other landscape and the lives of the things that live here. It's breath-taking to realise the responsibilities knotted into our connectedness.

Which makes it breathtaking, too, to realise that amongst this richly packed marine biosphere, new organisms are still coming to light, adding more pieces to the story of this particular green zone, to the life of the GBR as a whole, and to the ongoing revision of the catalogues of what is extant on the planet, right now.

The ecosystems of Lady Elliot Island are the southernmost of the reef, offering a last refuge for species seeking refuge from ocean warming – and a record fo what we stand to lose.

It underscores one aspect of the work this FIFO team of scientists is doing, introducing more and more of the entities with whom we share the world. The whole of what we call the whole world is still being revealed.

Layers of knowledge

Along the shoreline of Lady Elliot Island are pieces of pumice stone, sea-smoothed pebbles, dried out sea plants that look like intricately folded origami flowers. I rub one small grey stone disc between my fingers, registering its smoothness before I balance it, carefully, on another. And I turn the word *accretion* over in my mind.

Accretion is a word often associated with corals – they're animals, as we are, which exist in

Welcome to the family?


Priolepis sp. 1c


Trimma cf benjamini


Pomacentrus cf nagasakiensis


Trichonotus cf halstead


Eviota occipital spot d


Tomiyamichthys cf oni 6


Amblyglyphidodon cf curacao 8


Tomiyamichthys cf latruncularius


Eviota cf prasina


Ctenogobiops sp b


Eviota sp 2

"Some people are surprised that we continue to find new species at a fairly good pace," says Gerry Allen of Lady Elliot's putative new fishes. "People simply haven't paid attention to detail, haven't looked closely enough – there's still a lot of excitement." The collections are the beginning of months of taxonomic and genetic work towards publishing any descriptions of ultimately distinctive and confirmed new species.

And one simple reason the team may be finding new gobies on this part of the GBR? Maybe there's never been a goby expert looking here before. "Gobies are the most speciose of all the reef fish families," says Erdmann, "and probably the most overlooked as well. The tiny little dwarf gobies, they're literally the smallest vertebrates on the planet. Then there are shrimp gobies, a decent sized animal, but people tend to swim over them because they're camouflaged down on the sand. Perhaps it's not surprising that they would have been overlooked in this area – if previous scientists were looking at parrotfishes and sharks and butterfly fishes and the more conspicuous fishes." So much more to see.

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LADY ELLIOT ISLAND

interconnected communities that rely on each other for survival, as we do. A single 'coral' is made up of thousands of polyps, invertebrates no bigger than a pinhead.

Corals grow by asexually producing more polyps, each an exact replica of its parent. When a polyp reaches a certain size, it can divide. With enough replicas, the coral becomes a colony – some of which can reach several metres in height and width. Reefs grow through these multiplications of material; tiny, identical organisms; more and more and more.

Inside each polyp lives another even smaller animal, a zooxanthella – another ingredient in this creative combination. The zooxanthellae are single-celled dinoflagellates that help their corals survive, providing not only most of the corals' colour, but most of their nutrition as well, thanks to photosynthesis. Animals, all the way down.

This is often where a story turns to bleaching: when ocean water is too warm, it stresses the coral's zooxanthellae. They turn toxic and they leave the coral – but they are the coral's source of life. And even healthy reefs like Lady Elliot's show evidence of bleaching taking place.

"The corals are paler out there already," Townsend told me, "but not dead yet. They really are surprisingly resilient." It's one of her jobs during this expedition to photograph transects of these corals – an accretion to complement bleaching's attrition: building up knowledge as the corals' own communities begin to dissipate.

Coral are animals, as we are, which exist in interconnected communities that rely on each other for survival, as we do.

But in some ways, these ideas of growth, of accretion, of change, mirror the accretion of the Great Barrier Reef's own story. The first observations of its creatures, and intersections with them, came from the 70 different groups of First Nations Australians who cherish connection with the GBR's sea country – before the arrival of European ships with their navigators, their natural historians, their other ways of seeing.

Those ships must have slid over the surface, unable to see most of the richness below the water's surface while their hulls occasionally snagged and gashed on vast sharp coral outcrops. And then, in the last years of the 19th century, came William Saville-Kent, an English scientist and pioneer of sustainable fisheries. His are the

TOURISM AND EVENTS QUEENSLAND

first concerted Western portrayals of some of the species that live in these waters, published in *The Great Barrier Reef* in 1893. On his shoulders stand the next generations of ichthyologists, marine biologists and ecologists – all able to dive deeper, and for longer; to catch richer photographs; to see more.

And what strikes me, as I balance another smaller stone to finish off my triptych, is that so much of this – like the very structure and function of ecosystems – is about connection and relationship. And that the collection and transmission of knowledge is a particular preparation for the future.

I'm thinking about Jessica Blackmore, one of the Island's environmental officers, talking about work she'd done reining in some corallivores – drupella snails; crown of thorns starfish. One starfish aggregation – around 250 – had been culled just ahead of breeding season, stopping them in their tracks. "We managed to stop them spawning," she reported. "We made a difference." Then she paused. "But we can't stop the bleaching."

One moment of care, one available act, undertaken in one place.

This work not only prepares for the future, but trusts that that future is coming. And to do work so actively tilted towards tomorrow – what might happen; what might happen next – that feels like more than hope and optimism. It feels like love.

One aspect of collecting that's changed is the importance of recording context: "not just sampled at 5m depth," says Erdmann, "but 5m depth in a current-swept area of low hard-coral cover and lots of algae".

Nothing is ever all or nothing, no matter how big or how small ... Each is an aspect of something far greater

Irreplaceable wonder

When David Attenborough was asked where he'd like to go for the last documentary he'd travel to make, he nominated the Great Barrier Reef. "There's no equivalent anywhere else in the natural world of such splendour: all of these things moving through an architecture of coral," he said. "You never know what you're going to see when you turn the corner – it's far more obviously exciting and visually thrilling than, say, the tropical rainforest ... It's like the Christmas windows at Harrods."

At home, at the end of my time those 80km off the Queensland coast, I'm evangelising for weeks, but I can never quite capture the sense of the richness, the complexity, not just of the reef, but of the story I'm trying to tell here.

The importance of each individual brilliance – a beautiful fish, a new fish, a pinhead of a polyp that contributes to a coral's being – against the irreplaceable wonder of this reef as a whole. Nothing is ever all or nothing, no matter how big or how small it might be. Each is an aspect of something far greater, a planetary system, and that includes us as well.

Us and our relationship with – and responsibilities to – everything right down to a new and unnamed fish, swimming in a plastic bag, and what it might tell us of how things are and how they might be, as the climate changes and, we have to hope and work for, then changes again.

To witness these scientists at work, tracking things, finding things, monitoring things; to watch them identify and piece together new parts of the puzzle that is this one part of the world; to watch them pay attention to what is happening here: it is wonder and care, and it's love. Not bad approaches to bring to any part of the world on the lip of the Anthropocene, and on the brink of so many tipping points.

"I just love this project," says Mark Erdmann. "They're looking at everything in this little microcosm – from nutrient flows to birds and how that's probably affecting the reef. All the fine-scale biodiversity stuff: we've got 25 new fish records in three days. It's mind-boggling, and it's awesome. It's just going to continue to give insights that will hopefully allow us to much better manage a number of other reefs and small islands on the planet.

"And what better natural laboratory than one which is in really great shape, where the library is still relatively complete, right?"

ASHLEY HAY is based in Brisbane. Her most recent story for *Cosmos* was on the artist Tomás Saraceno, last issue.

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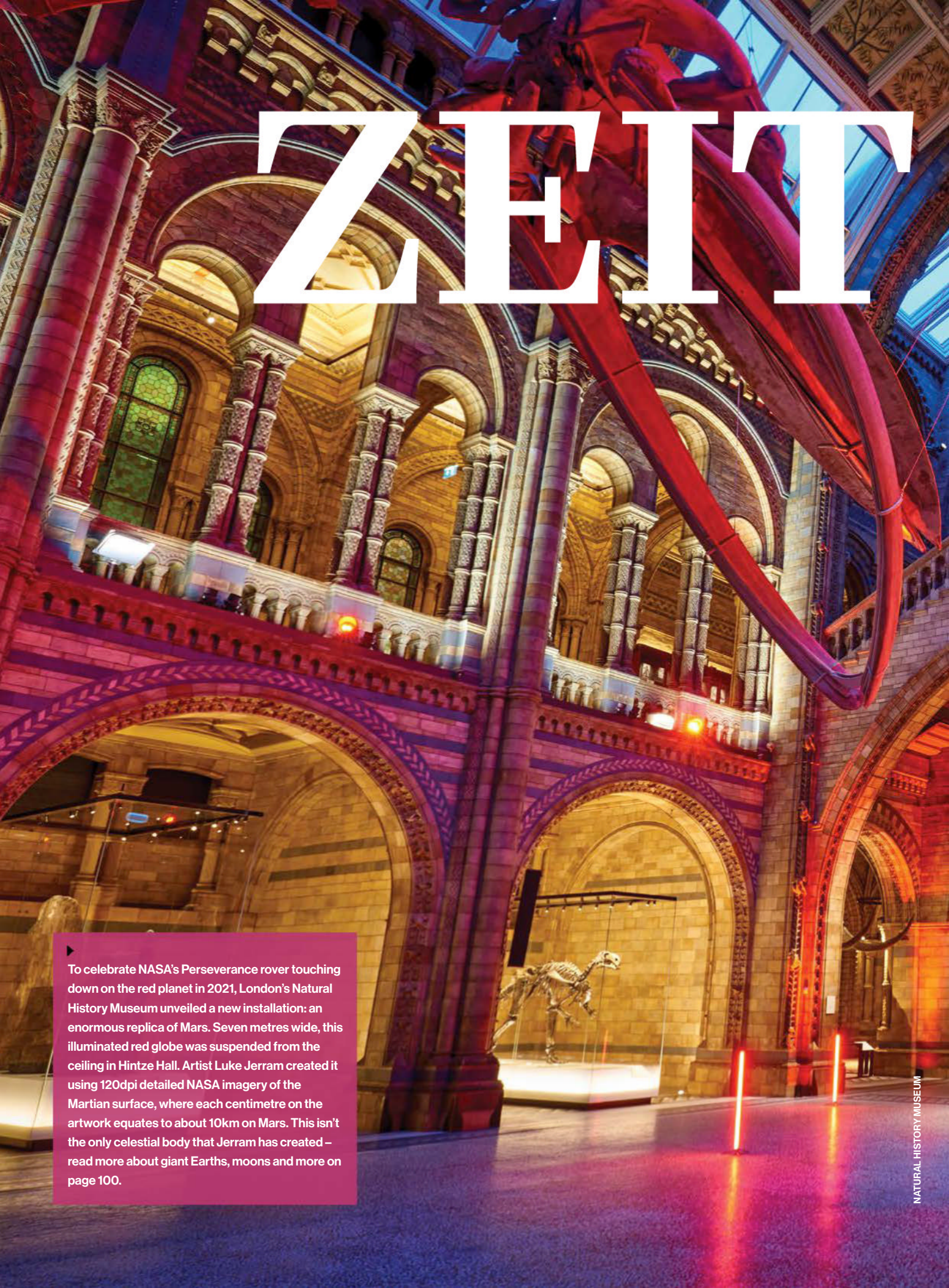
ZEIT



To celebrate NASA's Perseverance rover touching down on the red planet in 2021, London's Natural History Museum unveiled a new installation: an enormous replica of Mars. Seven metres wide, this illuminated red globe was suspended from the ceiling in Hintze Hall. Artist Luke Jerram created it using 120dpi detailed NASA imagery of the Martian surface, where each centimetre on the artwork equates to about 10km on Mars. This isn't the only celestial body that Jerram has created – read more about giant Earths, moons and more on page 100.

NATURAL HISTORY MUSEUM

GEIST

› Science meets life

MIDJOURNEY

Guess what's coming to dinner

The future of food is here, with lab-based meats being trialled and a cornucopia of plant-based products already stacked on shelves. **Jacinta Bowler** unpacks the what, why and how of meat 2.0.

There's nothing better than a barbecue on a hot day. But actual meat is now not the only grill goods on offer: it seems like new types of meat-free sausages, schnitzels and salami appear on the supermarket shelves every other week.

But how are plant-based meats actually made? And when are we likely to see cultivated (better known as lab-grown) meat available on shelves? Plus, are either of these options a cut above the real thing?

Let's tuck into the science of fake meats.

What is real meat?

To understand what fake meats are trying to imitate or replicate, first we have to understand good ol' regular meat.

Let's use beef as an example. A beef burger patty is a mix of fat and muscle tissue from a cow. A patty might be in the realm of 20% fat and 80% muscle tissue.

When it comes to beef patties you might think of a piece of perfectly marbled steak being ground up into mince. That's how it happens if you grind your own meat, but at the commercial scale things are a little different. To get the right percentages of fat and muscle tissue in the burger, butchers will mix meats from a bunch of different cows, and they can even be from different countries.

Protein filaments in the muscles – which normally make the muscle contract and relax – are what makes meat chewy. When a patty is cooked, the muscle fibres shrivel and coagulate – this is why the patty shrinks down when it hits a barbecue. But it's the melting fat that gives a burger that real mouthfeel and flavour. The higher the fat percentage (up to around 30%), the tastier – but also sloppier – the burger.

You might think the red juice you see coming out of a burger when it cooks is blood. Actually, it's water expelling from the muscles, mixed with an oxygen-carrying protein called myoglobin.

Plant-based meat

As a vegetarian I'd be the first to say that plant-based meat has gotten significantly more pleasant in the last few years.

The key driver is not what ingredients are used, but the development of better techniques to make it more meat-like.

What goes into a burger patty has mostly stayed the same – the protein might come from soy, wheat, pea, fungi or fava. The fat normally comes from coconut oil or vegetable shortening, which are solid at room temperature and melt as they heat up. But how these ingredients are processed makes a big difference.

Originally, some plant-meats were made with a technique called "shear cell processing". These products have a spongier texture, and they don't need refrigeration.

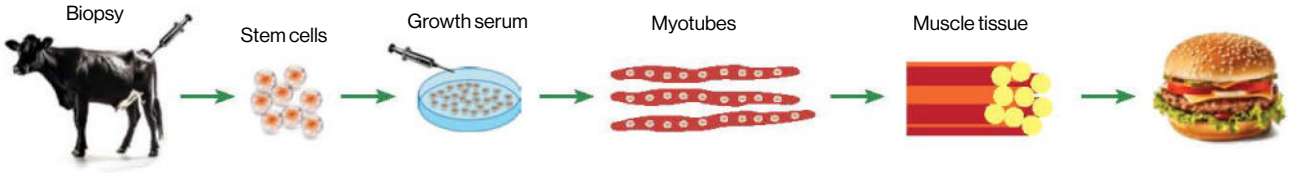
Nowadays, it's all about extrusion. Ingredients, water and oil are mixed together and pressurised through a teeny tiny hole called a die. In a technique called "high moisture extrusion", the protein is also heated in the extruder machine itself and then quickly cooled down to create fibres that mimic the muscle in a real animal.

"I think the plant-based meat industry has had so much amazing innovation over the past decade," says Dr Bianca Le, the founder and chair of Cellular Agriculture Australia.

"Plant-based meats today versus where they were five years ago – drastic difference, and that is because of this extrusion technique."

It's not just the texture that's changed – in newer fake-meat burgers, you might also see a red tinge. A company called Impossible Burgers creates this colour using a genetically engineered plant-based version of heme, the iron-carrying molecule also in myoglobin. However, you might be more likely to have had Beyond Meat burgers, which just use beetroot extract for a similar effect.

STEM CELL TO MEAT



One day when you're chowing down on your lab-grown burger, you might wonder about the process from farm to plate. That juicy beef in your mouth really did come from a cow – but was raised in a petri dish instead of a paddock. First, a sample of stem cells is taken from a live animal, fed in a lab and stimulated to turn into muscle or fat. The cells are then assembled into a meat-like structure using tissue engineering. Bon appetit!

But what about health? Comparing schnitzels to schnitzels, it's not as different as you might think.

A study last year from the George Institute for Global Health looked at 132 plant-based meats and 658 regular meats, all available in Aussie supermarkets. This included a huge variety of products like burger patties, sausages, bacon, chicken and meat in pastry like sausage rolls.

Both the plant and animal products had around the same levels of processing and contained similar amounts of protein. But plant-based meat products had more fibre and a lot less saturated fat and sodium than the animal meat products.

There was one downside to the plant-based versions: only 12% were "fortified" with important nutrients like iron, vitamin B12 and zinc. Although they can also be found in certain plants, most people get these vitamins from animal products.

Unfortunately, many of the foods – both meat and plant based – were considered to be "ultra-processed", a category that includes pizza and doughnuts. So they're definitely a sometimes food.

Lab-grown meat

What if you didn't need to worry about pea protein and coconut oil? What if you could just have real beef, minus the cow?

Hear more about future food and other cutting-edge science on our podcast: *The Science Briefing*

That's the promise of cultivated meat (also called lab-grown meat). But does it live up to the hype?

"Cell cultures have been around for decades. They've been scaled and used for commercial production of antibodies, medicines, drugs," says Le. "Now it has been used for food for the first time."

The not-so-secret ingredient in cultivated meat is stem cells. These are cells that can replicate and form all the other types of cells in the body. A lab-meat maker only has to take a sample of skin the size of a rice grain from a living animal – from a cow's ear, for instance – to start the process.

The next step is to chemically reprogram the cells using molecules called Yamanaka factors that target particular areas of DNA, causing them to revert to stem cells. The cells get turned into a cell culture line – that's a population of genetically identical cells descended from one cell – which replicates and can be turned into either muscle tissue or fat as the stem cells differentiate.

"You put [these cell cultures] into the bioreactor, which is a big stainless-steel tank – think of a brewery tank," explains Le.

"You feed it cell-culture media and then the cells grow in that tank. After however many days

WHEN WILL SEE CULTIVATED MEAT IN AUSTRALIA?

Australia might see cultivated meat on the shelves in the next few years. A company called Vow is the first to start the process of getting their cultured quail meat approved by Food Standards Australia New Zealand. Vow has also produced a "mammoth" meatball, by combining the DNA sequence for mammoth myoglobin with elephant DNA.

Another company, Magic Valley, is trying to cultivate more familiar meat – pork and lamb. Andrew Laslett, head of research and development, told *Cosmos* that they are hoping to get a product to regulators by the end of the year.

"That's ambitious, but that's what we're aiming for," he says.

"Very best-case scenario, we could have a regulated product by the end of 2024, but more likely sometime in 2025."

TOP: GREG BARTON. LEFT: WUNDERMAN THOMPSON / VOW

MIDJOURNEY

or weeks ... you're going to get a massive expansion of cells. Then you just harvest it."

You can think of the cell-culture media as food. It's typically made up of plant-based amino acids, proteins and glucose, but in smaller quantities than what needs to be fed to a cow for an equivalent amount of meat.

Mix the fat and muscle tissue together like they do with real meat and presto – instant burger patties! However, at that point you only have a bunch of fat and muscle cells. This is fine for things like minced meat and burger patties, but for products like steaks or bacon, you'd have to create a scaffold to put the cells into to give it the right shape and texture.

Interestingly, Le thinks that cultivated meat makers might be able to use some of the plant-based extrusion techniques to get these kinds of textures, but it isn't the only game in town – 3D printing and other techniques are also being researched.

The scaffolding part of the process is still in development, so even when cultivated meat becomes available in Australia, expect mince, not larger cuts of meat.

Unlike plant-based meat, cultivated meat isn't more or less healthy than regular meat because the meat cells are the same – the only difference is how it's grown. But how does it taste?

Le is a meat eater, and she reckons that cultivated meat tastes exactly like the real stuff.

If you're a foodie, though, you might be thinking about how a meat's flavour is a mixture of genetics, provenance and what it's fed – how would this work with lab-grown meat?

"If you think about the food that animals eat, that's basically what we're adding into the media that the cells are growing in," says Professor Andrew Laslett, head of research and development at an Australian cultivated meat startup called Magic Valley.

"There's an opportunity there to influence the tastes by adding different plant-based materials to the media."

Singapore has had a cultivated chicken nugget on the market for more than two years, so hopefully it won't be too long until we can all try some and confirm.

Is fake meat better for the planet?

One of the big selling points of both plant-based and cultivated meat producers is that these products take fewer resources to make.

This is particularly true for plant-based meat. A study by Johns Hopkins University researchers in the US found that protein for protein, the average greenhouse gas footprint for plant-based burgers was just 7% of beef, 37% of pork and 57% of chicken.

Cultivated meat is still in its early stages, so it's hard to make an exact environmental comparison. But a study published last year in *The International Journal of Life Cycle Assessment* looked at a hypothetical life cycle assessment of cultivated meat production in 2030. They found that cultivated meat could be almost three times more efficient at turning crops into meat than chicken is.

"Modelling that has been done shows that as long as you power the factories that are making the cultivated meat using an alternative energy source, it's better for the environment than traditional agriculture," says Laslett, who worked for CSIRO for more than 10 years before joining Magic Valley.

"Because it's such a new industry that's just starting off, there's the possibility of designing it to be really quite circular and sustainable."

Laslett suggests the industry could implement solar arrays, recycle media or use waste products to grow more crops to produce the 'feed'.

So by 2030, the sky's the limit on what you might grill. Companies are testing grouper, bison and even peacock, and the possibilities of plant-based are endless. One company in the US is even combining cultivated pig fat with plant-based meat to form bacon and other pig products.

The only sure thing is that the animals themselves are no longer required.

HUMAN WITHOUT THE HUMAN

"Cellular agriculture" isn't just making meat. Any kind of animal or plant product could be created in a vat.

Stem cells have been used in medical applications for years – think of cell therapy or drug testing. Anything that needs fresh human cells can use stem cells to create them. One example is creating beta islet cells (which make insulin) to treat diabetes.

Plants too have stem cells and can be used in similar ways, though they contain different nutrient amounts than a human stem cell.

Now, new cellular agriculture startups are expanding the possibilities, and ideas are getting wilder.

"People are producing real leather without the animal," says Le. "Some people are producing palm oil and coffee and chocolate."

Lab-grown coffee has more than a million cells, so it can be ground even finer than you're used to.

"You can apply cellular agriculture to making real dairy milk without the cow," says Le. "There's even a company in Melbourne called Me&; they're producing human breast milk without the human, for babies who are premature and their mothers aren't lactating yet."

JACINTA BOWLER is a science journalist at *Cosmos*. Their last story, on the SKA, appeared in Issue 98.

In 2020, the illuminated 3D art installation Gaia was exhibited in the Painted Hall at the Old Royal Naval College in London, as part of the Greenwich & Docklands International Festival.

DOUG SOUTHAL

THE ART OF THE PLANET

One artist has combined tech, philosophy, sound and setting to give modern humans a reminder of something desperately important: the fragility and isolation of Earth. **Matthew Ward Agius** reports.

Craning my neck, I see, floating above me, a massive, softly illuminated, whitish orb. As I step back, its true identity is revealed: blue swims into view, so too shades of brown and green.

It's a crystal-clear replica of our home planet.

And after nightfall, here at the WOMADelaide world music festival on a warm March evening at Adelaide's Botanic Park/Tainmuntilla, it's an unmissable sight.

Called Gaia, after the mythological personification of the Earth, this seven-metre-wide floating sphere has drawn dozens of humans into its orbit: revellers putting their feet up after a hot day marching between sound stages; friends sitting beneath, bathing in its gentle glow; mothers circling its perimeter with bubs in prams.

Festival-goers gather around Gaia at WOMADelaide in Botanic Park/Tainmuntilla in March 2023 (above), while on the opposite side of the planet, Gaia's larger cousin Floating Earth (right) sinks into London's Canary Wharf at the 2023 Winter Lights festival.

About 200 metres away, a much-hyped circus performance – *Place des Anges* (Place of the Angels) – is underway. It provides a curious contrast to the graceful Gaia – at one point, tonnes of white feathers are ejected by acrobatic "angels" onto the crowd below. As the illuminated duckdown drifts in the background, I'm struck by what Gaia asks the viewer: to consider the impact humans are having on our delicate world.

At least that's what Gaia's creator, acclaimed British artist Luke Jerram, intends.

"Gaia is an acknowledgement that we're in the sixth mass extinction of species on our planet," Jerram says. "There is a climate crisis. [Gaia] is not about raising awareness of climate change, it's about shouting as loud as we can that we really need to do something very quickly to avoid runaway climate change and all those horrible tipping points that are going to be kicking off."

> "Gaia is not about raising awareness of climate change, it's about shouting as loud as we can that we really need to do something very quickly."

As with all art, meaning derived by the viewer is subjective, and influenced by many factors. With fewer live acts, observers have longer, quieter moments to appraise Jerram's globe. During the day, however, Gaia grabs the attention of virtually every festival-goer, if only to provide a novel prop for a social media post.

While the interpretation of the artwork might be influenced by its setting, Jerram nevertheless sees an important role for his art – and all art – in motivating and informing people of science, and the fragility of our world.

"If you're a scientist you can apply your scientific understanding and knowledge to it," he says. "If you're a banker, you can divest your fossil fuel investments. If you're a musician, you can communicate in that way, and as an artist, I'm able to create strong and powerful images."

Inspiration is clearly not a challenge for Jerram, but putting such a large piece together is no mean feat, and one that's only become truly possible in the last decade

SAIGE PRIME

JOSEPH OKPAKO/GETTY IMAGES

At the very beginning of his career around two decades ago, the now 49-year-old artist from Bristol, in south-west England, first imagined a large, true-to-nature facsimile of the Moon.

Jerram was inspired by living in Bristol, where he noticed the huge tidal variation as he cycled each day over the New Cut – an artificial diversion of the tidal River Avon – built in the early 19th century to accommodate dockland construction in the city centre.

Jerram wanted to create something that viewers could see up close, allowing them to more clearly observe the unique geographic characteristics of our lunar neighbour. But the manufacturing techniques and imagery needed to realise such a sculpture simply weren't available.

Then, in 2009, the Moon-destined Lunar Reconnaissance Orbiter launched. It uses a special camera system mounted to its body to relay high-resolution images of the Moon's surface back to NASA. Jerram selected a series of these photographs and the US Geological Survey's Astrogeology Science Center compiled them into the 23-metre-wide, ultra-detailed image that would form the basis of his first balloon creation.

Jerram approached the world's most prolific maker of hot air balloons, Cameron Balloons, conveniently located just minutes from the centre of Bristol, to help bring his idea to life. In 2016, the seven-metre-wide Museum of the Moon was filled with helium and hoisted into the air at the Bristol Balloon Festival.

Museum of the Moon's success at Bristol led to tours of Britain, Europe and, eventually, the world: it's been seen by more than 20 million people in more than 30 countries. It enabled Jerram to

TOP: SAIGE PRIME. LEFT: ROY RILEY.

"Mars" appeared at London's Natural History Museum in 2021 (above), with "every valley, crater, volcano and mountain ... laid bare for us to inspect", according to Jerram. Later that year, Gaia and visitors alike were suspended in the forest for Dorset's Inside Out Festival (opposite).

CHRIS JACKSON/GETTY IMAGES

consider new projects in that vein: first, Earth – Gaia – and more recently, Mars.

Gaia is not the same as its lunar predecessor, however. The print is a unique compilation of images from NASA's Visible Earth series, drawing contributions from dozens of spacecraft and satellites put into space throughout the last decade.

Half the Earth is always bathed in sunlight, but these images are reassembled to provide a fully lit rendition of the planet's surface.

Cameron Balloons prints this image at 120dpi – the number of ink dots placed within a square inch of material – onto 50 nylon balloon fabric panels using massive caravan-sized printers. These panels are then carefully sewn together at Cameron's Bristol headquarters.

> "We've been staring at the Moon for 200,000 years, so we've got all these mythologies and stories and cultures related to looking at it, whereas it's only been 60 years since we've seen the Earth from space."

To illuminate the structure, an internal light source is inserted into the helium-filled balloon and a motorised fan is used to help give Gaia its body.

Wires are then attached to the planetary poles and Gaia is hoisted into place. Interior exhibition venues attach the wires top and bottom, which allow Gaia to slowly rotate on its vertical axis. Outdoor events – like WOMADelaide – rely on cranes to secure the globe above its staging site, in which case rotation isn't possible.

And although not feasible at a major music festival, where waves of sound wash across Gaia's exhibition patch, the exhibit usually employs its own musical soundtrack – compiled by Jerram – to "steer" the interpretation of the exhibit. The track incorporates NASA audio recordings of astronauts observing the planet, children offering their perspectives on climate change, whale calls and ocean sounds.

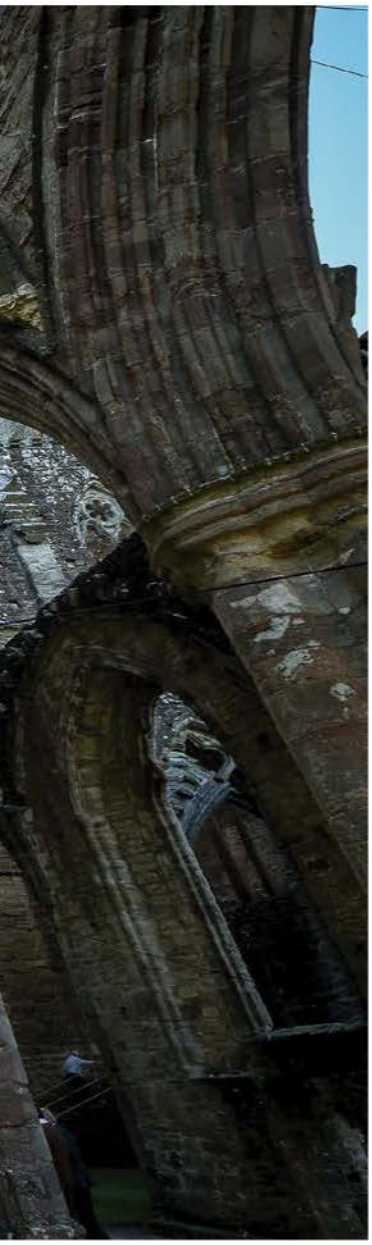
What would you think if you were standing on the Moon and the Earth rose above the horizon? Awe-inspired? Terrified? Serene? Sadly, few humans have been in that privileged position.

But stand about 200 metres away from Gaia and it will appear at the size you would see Earth if you were standing on the surface of the Moon. The emotional state one experiences when doing this has a name. The so-called "overview effect" was first coined by space philosopher Frank White in 1987 to help describe the perspective-bending sensation that first seeing the Earth from space imposes on the minds of astronauts, a "beyond-words" Zen-like feeling. Recently, White suggested the sensation might also be achieved via commercial spaceflight or virtual simulations.

And, certainly, that's the effect Jerram is going for: putting Gaia's Earthbound observers into a position where they too might consider the planet's impressive, yet vulnerable nature.

"We've been staring at the Moon for 200,000 years, so we've got all these mythologies and stories and cultures related to looking at the Moon, whereas it's only been about 60 years since we've seen the Earth from space," Jerram says.

TOP: BEN BIRCHALL/GETTY IMAGES. LEFT: SAIGE PRIME



"In the Apollo 8 mission, the astronauts saw the Earthrise, and it had a profound effect on them, realising just how beautiful and fragile it is, how we're all interconnected.

"I'm hoping it gives the public a sense of what the overview effect is like, that experience astronauts get when they first go into space, and they look down at our planet for the first time, and become overwhelmed by the beauty and wonder of it all."

But Jerram is equally happy to reimagine his works to send more deliberate messages. Gaia, for instance, has a slightly larger cousin – the Floating Earth. At 10m in diameter, it's otherwise identical. However, instead of Gaia's mid-air suspension, it's presented as a globe dipped in water.

The effect is achieved by sinking concrete to the bed of a water body, with chains connected to a pontoon at the base of the globe.

> "Floating Earth affords a more challenging view. Observers see the Earth ever so slightly sink into the water beneath it: a metaphor for the planet's current state of affairs."

NATIONAL ENVIRONMENT RESEARCH COUNCIL (NERC)

For Jerram, this experiment sees meaning shift based on setting. At one point, Floating Earth was placed in a lake that fills an old mining quarry.

"That felt quite positive," says Jerram.

But at the beginning of 2023, Jerram placed the Floating Earth on dockland waters at Canary Wharf, a London commerce hub and home to some of the world's biggest companies – including major fossil fuel extractors BP and Chevron, plus the financial institutions that keep them afloat.

Gaia offers onlookers a chance to reflect on the fragility of the planet as if experiencing the overview effect for themselves, but Floating Earth affords a more challenging view. Observers see the Earth ever so slightly sink into the water beneath it: a metaphor for the planet's current state of affairs.

The heavens were brought down to Earth at the 2018 Wye Valley River Festival, when artist Luke Jerram (below) hung his seven-metre installation "Museum of the Moon" in the ruins of Tintern Abbey in Chepstow, Wales (left).

The Canary Wharf placement had such impact that neighbouring banks approached Jerram, seeking to attach their names to the project. Such offers were promptly rejected by the artist, who avoids air travel now to minimise his personal carbon output. Corporate greenwashing – from big carbon emitters or the institutions that support them – doesn't sit well with him.

"What I'm trying to do is create artworks, and do work that isn't going to be detrimental to human health, or the environment, that's generally my policy," Jerram says.

Jerram's most prominent Gaia commission came two years ago at COP26 – the United Nations Climate Change Conference in Glasgow. There, it loomed over the plenary hall as a constant reminder to world decision-makers of the impact of their negotiations.

WOMADelaide's isn't the only Gaia on Earth today. Jerram has another gracefully rotating in the ornate Frauenkirche – a cathedral in Dresden, Germany. Others will be inflated at venues around the globe in the weeks and months to come.

Prior to WOMADelaide, Gaia's Australian display venues have included Perth's Joondalup Festival, HOTA on the Gold Coast, Melbourne's St Paul's Cathedral and Brisbane's West End. This year, Gaias will pop up in an Italian Castle, churches across the UK and installations in Canada.

MATTHEW WARD AGIUS is a science journalist at *Cosmos*. His story on Bond gadgets appeared in Issue 97.

DEAD COOL SCIENCE

NAUGHTY DOG/HBO

From parasitic wasps to body-hijacking fungi, the natural world is full of real-life zombification. But could our favourite post-apocalyptic TV shows come true? **Imma Perfetto** investigates.

The Last of Us, *The Walking Dead*, *World War Z*, *Zombieland*, *Shaun of the Dead*... I could keep going but I think you get the gist.

Zombies are everywhere in fiction, from movies to TV shows, video games to books.

These stories are usually pretty hand-wavey about the actual science that has turned humans into mindless, shambling, killing machines, but you might be surprised to know that there are actually some pretty gruesome examples of zombification in real life.

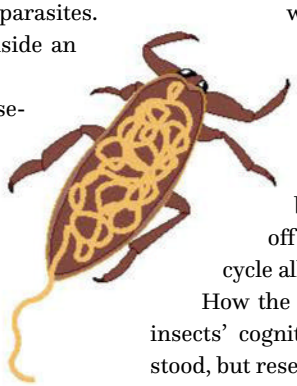
If you can stomach it, come with me on a tour into the lives of parasitic wasps, worms, single-celled organisms, fungi, viruses – and even into our own brains.

Horror authors and script writers, listen closely – because we all know that some of the scariest stories are the ones rooted in reality.

NOT YOUR TYPICAL SWIMMING LESSON

The first stop on our super fun and not-at-all distressing zombie extravaganza is parasites. These are organisms that live on or inside an organism of another species, its host.

Gordian worms, also known as horsehair worms, are long, thin parasitic worms found in fresh water all over the world. The larvae bore into the body of a host, initially other larvae in the water, which then get snatched up and eaten by unfortunate insects like grasshoppers or crickets. There, the worm grows inside the insect's body cavity to as long as 30 centimetres, secreting digestive enzymes from their skin to absorb their host body's nutrients.



If that isn't spine-chilling enough, it gets worse. Hosts infected with a gordian worm will, despite avoiding water in all other cases, perform a deadly cannonball into the next aquatic environment they come across and drown. The worm then bursts out of a borehole and swims off in search of a mate, starting the cycle all over again.

How the worms manage to manipulate the insects' cognitive functions is not fully understood, but researchers believe the worms produce molecules that act on the development of their host's central nervous system, thus altering physiological responses and behaviours.

HOME SWEET ZOMBIE SPIDER HOME

If those tapeworms from hell made you squeamish, get a sick bucket ready because there are far worse parasites to contend with.

Nature is rife with examples of parasitic puppeteers infecting their host and inducing some pretty strange behaviour. One of my favourites is from a 2018 study published in *Ecological Entomology*, which discovered a previously unknown species of wasp deep in the Ecuadorian Amazon jungle – with the ability to transform a species of spider into a zombie-like drone.

These spiders (*Anelosimus eximius*) are known for living together in large colonies, where they cooperate to hunt and parent. Think Aragog and his giant Acromantula children chilling together in Hogwarts' Forbidden Forest.

But the study, led by scientists from the University of British Columbia in Canada, found that *Zatypota* wasps intrude on this idyllic social life by laying eggs on the abdomens of the spiders, which then hatch into larvae that feed on the spider's internal body fluid. The larvae finally take complete control of the spider's body, hijacking its brain and triggering some unusual behaviour.

The researchers don't know yet how the wasps manage total control, but suspect it may involve the wasp larva injecting hormones into the spider.

The result is that the spider does something against its own behavioural tendencies: it leaves the colony and builds a densely woven, cocoon-like nest where the larvae can grow safely and comfortably into adult wasps, devouring their host in the process.

Delicious.

THIS FUNGUS IS TRENDING

We can't cover real-life inspirations for zombie apocalypses without talking about *Cordyceps*. It's possibly the world's most infamous fungus thanks to its starring role in the video games *The Last of Us Parts I* and *II*, as well as the live-action TV adaptation released earlier this year.

Cordyceps and *Ophiocordyceps* are genera of fungi that include about 750 species worldwide, most of which are parasitic and infect insects and other arthropods, like carpenter ants and trapdoor spiders. Infection starts when a fungal spore gets inside an organism, like an ant, and begins growing.

The ant's behaviour gets hijacked and it prioritises its parasite's reproduction over everything else. It stops foraging for the colony and communicating with its nest mates, becomes hyperactive and wanders off on its own to find a spot to climb up to.

It then chomps down on a piece of vegetation in a move called the "death grip". The muscles in its mandibles then atrophy, locking it in place for the final throes of its life.

The fungus consumes everything inside the host, killing it, then uses those nutrients to sprout a fruiting body out the top of the host's head. Spores form and drift off to infect more unwary hosts.

How is this piece of horrid biology possible? Again, it comes down to secreted chemicals and their effect on the host's physiology. For example, a 2015 study led by researchers at Pennsylvania State University in the US identified a range of secreted proteins produced increasingly by the fungi during the strange biting behaviour. These may affect a range of processes including immune responses, stress responses and impairing the production of chemicals used in communication between insects.

ALL ILLUSTRATIONS: GREG BARTON

Hear *Cosmos* journalists explain all of life's big and small questions on our weekly podcast: *Huh? Science Explained*

IT'S A VIRAL SENSATION

This deep-dive into grossity wouldn't be complete without mentioning rabies – the virus that inspired the zombies of the horror classic *28 Days Later*.

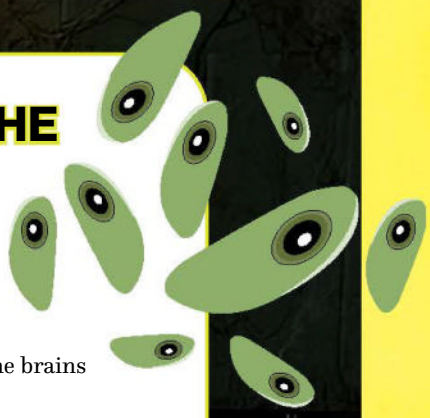
A rabies infection has all the symptoms of your typical zombie: a compulsive need to bite, a fear of light and mindless aggression. The virus is usually transmitted through bites and scratches from an infected animal, and it takes time to travel to the brain before causing symptoms – which is absolutely essential if you're going to have the requisite scene where a person tries to hide their bite, but gets progressively sicker until the group confronts them and finds out they're infected.

This incubation period typically lasts 2–3 months for rabies, but can vary from one week to a year. Rabies progresses to the central nervous system where it causes inflammation of the brain and spinal cord, triggering symptoms in two different forms.

There's paralytic rabies, which occurs in about 20% of human cases. Here, muscles become progressively paralysed, and the person falls into a coma before dying.

Then there's furious rabies, like your more *World War Z* flavour of zombie, which causes irrational aggression, hyperactivity, hallucinations and a fear of water and fresh air.

A CATASTROPHE WAITING TO HAPPEN



A little closer to home, there's the single-celled parasite *Toxoplasma gondii* that infects the brains of our kitty cats, and ours too.

A 2014 study published in *PLoS ONE* actually estimates that up to half of the world's human population is infected, though most of us have no symptoms. That's pretty alarming to contemplate, since *Toxoplasma* has been shown to change the behaviour of infected mice, who become hyperactive and lose their innate fear of cats – in some cases even appearing to be attracted to them.

There's evidence that also suggests toxoplasmosis might be linked to personality changes in humans too. One study found an association with impulsivity in younger men and increased aggression in women, while another found a positive association between national homicide rates and prevalence of the parasite in the population – although correlation is not causation.

I could keep going – there are so many more thrillingly grisly examples of zombification in nature – but you might need some fresh air and recovery time.

Just one more thing before you go. These examples of zombification fit the major zombie stereotypes: increased aggression, a loss of autonomy and a compulsion to bite or to ensure the spread of the parasite or virus infecting the host. But thankfully, there aren't any known diseases or afflictions in nature that can continuously

"Nature is rife with examples of parasitic puppeteers infecting their host."

reanimate corpses – so the undead remain firmly within the realms of fantasy.

Maybe that will help you rest easy at night – or maybe I've already infected your nightmares with mind-controlling worms and fungi that will consume you from the inside out.

Sweet dreams.

IMMA PERFETTO is a journalist at *Cosmos*. Her story on bananas appeared last issue.

WHERE IN THE COSMOS?

Send us a pic of where you're reading *Cosmos* to win a limited edition notebook.

Desert to the sea

Under the coolibah trees of Witchelina in far north SA – a former pastoral property, now a nature reserve – Martin Caon relaxes with *Cosmos* after conducting a fauna survey searching for lizards, dunnarts and planigales. Meanwhile, Rob Tagliaferri catches up on back issues while aboard the *Pacific Explorer* in Exmouth on the day of the solar eclipse. We'd love to see where you're reading! Send us your shot: contribute@cosmosmagazine.com.

GUESS WHO?

Question

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Hint:

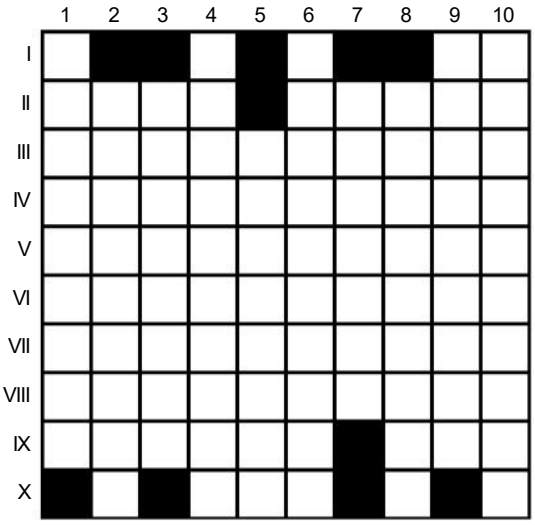
The law was postulated by two French scientists in 1819.

MIND GAMES

NO.25

Who Said?

"The purpose of life is the investigation of the Sun, the Moon and the heavens." (10)



Instructions

Answers to each of the clues in columns 1 to 10. Row IV reveals the answer.

Clues and columns

1 From the Spanish for 'little armoured ones', what are the New World mammals of the order *Cingulata*? (9)

2 What is the property of gels to become liquid when stirred or shaken? (10)

3 What adjective pertains to the valve-like structure that prevents food and drink from entering the larynx? (10)

4 What is 10 to the power of 9 of the SI unit of frequency? (9)

5 What is the study of earthquakes and how their shock waves travel through the earth? (10)

6 Which Australian yachtsman designed the winged keel? (3,6)

7 What is a device for enlarging or reducing maps? (8)

8 Named after an English mathematician, which form of algebra is used in logic where the operators are represented as 'and', 'or' and 'not' and are ascribed a true or false value? (7)

9 Usually a result of alcoholism or hepatitis, what is the chronic liver disease marked by the degeneration of cells, inflammation and thickening tissue? (9)

10 What is the common name of the precious stone, a variety of corundum, consisting of aluminium oxide with traces of iron, titanium, vanadium or chromium? (8)

COSMOS CODEWORD

NO.25

Codeword requires inspired guesswork. It is a crossword without clues. Each letter of the alphabet is used and each letter has its own number. For example, 'A' might be 6 and 'G' might be 23 .

Through your knowledge of the English language you will be able to break the code. We have given you three letters to get you started.

19	12	25	24	3	4	9	15 C	■	12	26	26	9	17	3
3	■	12	■	25	■	25	■	16	■	12	■	25	■	14
18	3	25	12	4	3	24	■	1	26	4	1	8	9	15
26	■	1	■	3	■	20	■	16	■	3	■	18	■	3
19	20	4	19	26	■	26	8	1	18	10	21	9	25	3
9	■	3	■	22 H	■	8	■	5	■	■	■	25	■	24
18	12	8	3	■	5	18	3	12	6	2	12	26	8	■
3	■	18	■	11	■	10	■	■	■	1	■	9	■	9
■	2	3	4	20	18	■	1	7	3	18	12	15	8	26
15	■	■	■	9	■	4	■	12	■	8	■	■	■	1
22	10	19 P	1	14	9	12	■	15	1	22	12	5	9	8
12	■	22	■	1	■	23	■	12	■	13	■	1	■	1
18	3	12	8	8	3	4	19	8	■	9	1	25	■	19
23	■	26	■	9	■	12	■	3	■	8	■	20	■	9
3	14	3	18	15	9	26	3	■	19	22	12	26	9	15

1	2	3	4	5	6	7	8	9	10	11	12	13
14	15	16	17	18	19	20	21	22	23	24	25	26

ALL PUZZLES DESIGNED AND COMPILED BY SNODGER.COM.AU

IT FIGURES

NO.25

	1	2	3	4
A				
B				
C				
D				

Instructions

Using the clues below place the numbers 1 to 16 correctly in the grid. How many clues do you need?

Level 1 – Chief Scientist

1. All the numbers with four or more factors are in the last two columns.
2. Dividing the second number by the third will give you the same result in all four rows.
3. The difference between the last two numbers in the first three rows is a multiple of the smallest number in Row A.
4. The sum of the descending numbers in Column 1 is equal to the product of the numbers in Column 2.
5. The square number which begins Row C has all its factors in the same row.

Level 2 – Senior Analyst

6. The second number in Column 4 is twice as big as the number immediately below it
7. All the multiples of 5 are in the top row.

Level 3 – Lab Assistant

8. The product of the last two numbers in Row C is 24.

SOLUTIONS: COSMOS 98

CODEWORD

O	X	Y	M	O	R	O	N	■	F	A	B	R	I	C
B	■	T	■	X	■	H	■	E	■	B	■	U	■	O
L	I	T	H	I	U	M	■	J	O	U	R	N	A	L
I	■	E	■	D	■	S	■	E	■	N	■	■	■	L
V	O	R	T	E	X	■	A	C	A	D	E	M	I	A
I	■	B	■	■	■	D	■	T	■	A	■	I	■	P
O	R	I	G	I	N	A	L	■	K	N	O	C	K	S
N	■	U	■	Z	■	N	■	G	■	C	■	R	■	E
■	A	M	A	Z	E	D	■	R	H	E	B	O	K	■
C	■	■	■	A	■	E	■	O	■	■	■	S	■	I
A	F	T	E	R	G	L	O	W	■	S	A	C	■	N
L	■	O	■	D	■	I	■	■	■	Q	■	O	■	S
I	M	P	A	S	T	O	■	T	R	U	M	P	E	T
C	■	I	■	■	■	N	■	E	■	A	■	I	■	E
O	R	C	H	I	D	■	H	A	N	D	I	C	A	P

1 N	2 P	3 U	4 X	5 G	6 H	7 E	8 S	9 Y	10 M	11 A	12 D	13 L		
14 Q	15 I	16 W	17 Z	18 J	19 T	20 V	21 D	22 F	23 R	24 B	25 K	26 C		

IT FIGURES

1	8	9	10
2	3	15	16
4	5	6	12
7	11	13	14

WHO SAID?

Immanuel Kant

Best known for his work in the philosophy of ethics and metaphysics, Kant is one of most prominent and influential figures in modern Western philosophy.

■	D	S	■	S	■	B	B	■	W	■	O	
A	I	P	■	U	V	E	E	B	I	P	B	
M	C	H	T	P	E	L	R	L	N	E	S	
E	K	Y	R	E	S	L	K	A	E	K	T	
R	S	G	I	R	P	W	E	C	C	I	E	
I	M	M	A	N	U	E	L	K	A	N	T	
C	I	U	S	O	C	T	E	B	S	G	R	
I	T	S	S	V	C	H	Y	U	K	M	I	
U	H	■	I	A	I	E	■	R	■	A	C	
M	■	■	C	■	■	R	■	N	■	N	S	

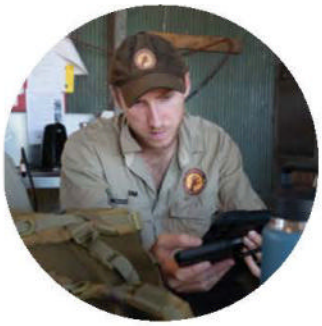
WHOSE LAW? ANSWER:

Within a broadly distributed taxonomic clade, populations and species of larger size are found in colder environments, while populations and species of smaller size are found in warmer regions.

Carl Bergmann

Chester Clarke

Archaeologist



Chester Clarke has an abiding passion to help protect Indigenous people and culture. A graduate of Flinders University, the young archaeologist has worked in South America and Asia but now holds a "dream job" in Arnhem Land, northern Australia.

The 28-year-old has helped survey areas of Cambodia to discover more about aspects of the ceramics trade between China and the Khmer empire, examined looted burial sites in Mongolia and worked closely with Indigenous people in Brazil, Peru and Bolivia.

Today, he works with the Bininj people of Western Arnhem Land in the Top End of Australia, shuttling between remote outstations to locate, study and preserve rock art that dates back thousands of years. As the rock art project officer for Warddeken Land Management, he works with Traditional Owners and Indigenous rangers to build up a database that records this aspect of their culture in perpetuity.

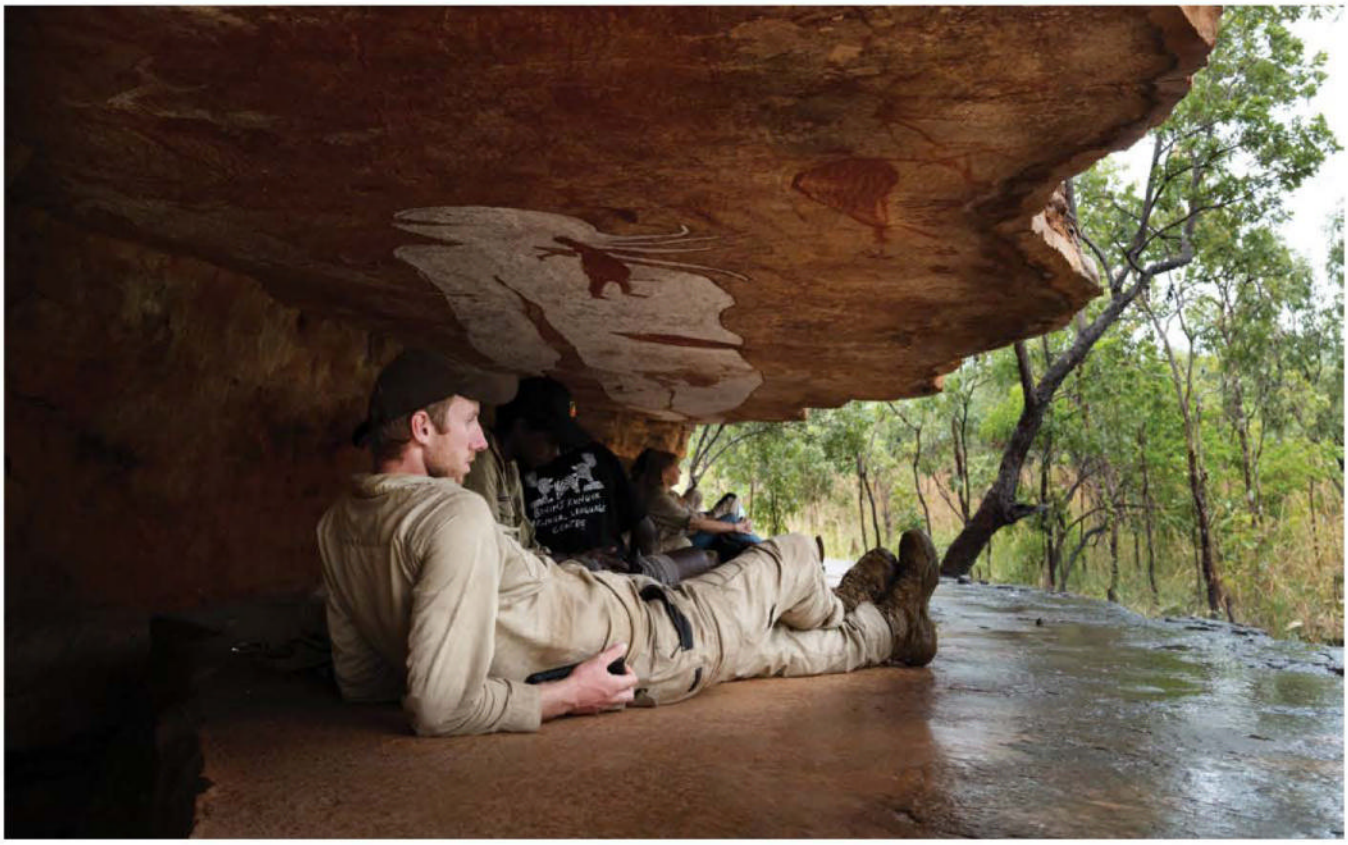
"Rock art is very vulnerable and it is imperative we protect these places," Chester says. "I started studying archaeology to help people and to try and make a positive change to protect cultural spaces now and into the future. I try to use my skills to help as many people as I can."

After three years working with Indigenous custodians, Chester says the exchange is definitely two-way.

"They are very knowledgeable people," he says. "I have already learnt much from Bininj people by being on their land, through their language, their practical skills and stories."

READ ABOUT THE RESTORATION OF NAWORO ON PAGE 44.

> Rock art is very vulnerable and it is imperative we protect these places.



DAVID HANCOCK

We're proud to have started publishing stories in our Greenlight Project: a year-long look at how regional Australia is dealing with climate change. People living and working outside Australia's cities faces huge risks and equally huge opportunities through the challenges posed by moving to a low-emissions future. How will they fare?

Our dedicated Greenlight team is going bush, to tell stories from across the nation about the people, places and industries working towards that future: facing climatic change and innovating to confront it.

Please join us – there's much to learn.
cosmosmagazine.com/Greenlight-Project

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